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OPTIMIZATION DESIGN OF KEY PARAMETERS OF SOLAR FLAT PANEL SOLAR COLLECTOR'S OWN STRUCTURE BASED ON PYTHON

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ОПТИМИЗАЦИЯ ОСНОВНЫХ ПАРАМЕТРОВ КОНСТРУКЦИИ ПЛОСКОПАНЕЛЬНОГО СОЛНЕЧНОГО КОЛЛЕКТОРА НА БАЗЕ PYTHON

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Abstract. Combined with domestic and foreign literature, the research progress, key parameters and existing problems of flat-panel solar collectors are analyzed. On this basis, the thermal efficiency of flat-panel solar collectors is studied by means of experiments and numerical simulations. This paper introduces and analyzes the structural characteristics of flat-panel solar collectors. Based on the structural characteristics of flat-panel solar energy and research at home and abroad, the influence of the structural parameters of each flat-panel solar collector on the collector performance was studied. According to the heat transfer process and structural characteristics of the collector, the heat energy equation of the collector is established, and the calculation process of the heat loss of the collector is simplified according to the existing research, and the calculation of the heat loss coefficient is an empirical formula. In order to facilitate the experimental study, an efficiency factor and a heat transfer factor are introduced, and the temperature of the fluid at the inlet of the collector is used to replace the surface temperature of the heat-absorbing plate, which is difficult to measure. The calculation program is used to obtain the influence data of each key parameter of the collector on the thermal efficiency and use Origin to process the data to visualize the influence of each parameter on the thermal efficiency. On this basis, a variance analysis method is proposed to optimize the collector. Based on the PYTHON software, the calculation program is written according to the variance analysis method, and the key parameters that will greatly affect the instantaneous efficiency of the collector are combined in pairs, and the optimal collector parameter combination corresponding to the maximum instantaneous efficiency is studied. This research has a certain guiding effect on the utilization of solar energy.

Аннотация. На основе литературных данных проанализированы ход исследований, основные параметры и существующие проблемы плоскопанельных солнечных коллекторов.

Исходя из этого, тепловой КПД плоских солнечных коллекторов изучается с помощью экспериментов и численного моделирования. В статье представлены и проанализированы структурные характеристики плоских солнечных коллекторов. На основе структурных характеристик плоскопанельной солнечной энергии и исследований было изучено влияние структурных параметров каждого плоскопанельного солнечного коллектора на производительность коллектора. В соответствии с процессом теплопередачи и конструктивными характеристиками коллектора устанавливается уравнение тепловой энергии коллектора, а процесс расчета тепловых потерь коллектора упрощается в соответствии с существующими исследованиями, а расчет коэффициента тепловых потерь является эмпирической формулой. Для облегчения экспериментального исследования вводятся коэффициент полезного действия и коэффициент теплоотдачи, а температура жидкости на входе в коллектор используется вместо температуры поверхности теплопоглощающей пластины, которую трудно измерить. Программа расчета используется для получения данных о влиянии каждого ключевого параметра коллектора на тепловую эффективность и использует Origin для обработки данных для визуализации влияния каждого параметра на тепловую эффективность. На этой основе предлагается метод дисперсионного анализа для оптимизации коллектора. На основе программного обеспечения PYTHON программа расчета написана в соответствии с методом дисперсионного анализа, а ключевые параметры, которые будут сильно влиять на мгновенную эффективность коллектора объединены попарно, а оптимальная комбинация параметров коллектора, соответствующая максимальной мгновенной эффективности, изучалась. Это исследование имеет определенное направляющее влияние на использование солнечной энергии.

Keywords: solar energy, collector, two-way ANOVA, PYTHON.

Ключевые слова: солнечная энергия, коллекционер, двусторонний дисперсионный анализ, PYTHON.

Due to the intensified energy depletion and greenhouse effect caused by the huge consumption of traditional fossil fuels, it is imperative to develop clean energy to optimize the energy consumption structure. In recent years, solar energy has been widely used in photovoltaic power generation, solar concentrating heat collection and thermoelectric hybrid systems [1, 2].

In solar thermal utilization, the development of solar water heating system has promoted the innovation of flat panel solar collector technology. Compared with evacuated tube collectors, flat-panel solar collectors have the advantages of less tube burst and long life, and are widely used in urban residential building integration. Experts and scholars at home and abroad have analyzed the influence of the parameters of the heat absorbing plate and the rain and dust accumulation in the external environment on the thermal performance of the flat-panel solar collector [3, 4] and used nanofluids as the working fluid to improve the thermal efficiency of the flat-panel solar collector. Chinese scholars [5, 6] have studied the effects of different boundary conditions, such as ambient temperature, working medium inlet temperature, working medium flow rate, and cavity absorber emissivity, on the heat loss of cavity absorbers [7-9]. The research of foreign experts and scholars has shown that porous media has a significant effect on the enhancement of heat transfer of flat-panel solar collectors and can effectively reduce the heat transfer loss of the collector [10]. Cruz-Peragon F et al. [11] used nonlinear optimization method to analyze the relationship between various parameter changes of flat-panel solar collectors and their thermal performance and established an energy equation based on genetic algorithm optimization. The non-uniform flow of the heat collector working fluid, the temperature distribution of the heat absorbing plate and the Nusselt number of the working fluid heat transfer in the tube are discussed, and the optimal design algorithm of the flat plate collector is given.

This paper focuses on optimizing the structural parameters of the flat-panel solar collector to improve the thermal efficiency of the collector. The key points such as the ambient temperature, wind speed, average temperature of the heat-absorbing plate, heat-absorbing plate and tube sheet of the collector are analyzed by using python numerical calculation method. The effect of parameters on the thermal efficiency of the collector.

The main working principle of the flat-panel solar collector is that the sunlight irradiates the heat-absorbing plate through the transparent cover plate, and the heat energy converted by the solar energy is transferred to the exhaust pipe, and the heat-collecting working medium in the exhaust pipe transmits the heat. The flat-panel solar collector is a special heat exchange device. The solar radiation first reaches the transparent cover on the upper surface of the collector. Most of the solar radiation reaches the surface of the collector through the transparent cover, and a small part is covered by the cover. The plate absorbs or is reflected back to the sky. Secondly, most of the solar radiation energy reaching the surface of the heat collector plate will be absorbed by the heat collector plate and converted into heat energy, and the heat energy on the heat collector plate will be transferred to the fluid channel wall in contact with it in the form of heat conduction, and a small part will be converted into heat energy. Reflected by the heat collector to the transparent cover. In this way, when the heat collecting working medium from the inlet end of the fluid channel flows through the fluid channel, it is heated by the heat energy transferred to the wall of the fluid channel. The working medium flows out from the outlet end of the fluid channel with useful energy. After such many cycles, the solar radiation energy is continuously absorbed and stored in the hot water tank for backup, becoming useful energy. At the same time, the transparent cover, the surrounding frame and the bottom of the collector lose heat to the environment, which constitutes the heat loss of the collector. Such a heat exchange cycle process is maintained until the heat collection temperature reaches a certain equilibrium point. Its basic working principle [12, 13]. It is mainly composed of heat absorbing plate, transparent cover plate, thermal insulation layer, exhaust pipe (heat collecting pipe) and shell and other components.

The instantaneous efficiency equation of a solar collector is the main basis for measuring its thermal performance. The effective energy and instantaneous efficiency of a flat-panel solar collector under steady-state conditions can be obtained from the following equations [14]:

$$Q_{\mathrm{u}} = A\left[S - U_{\mathrm{L}}\left(T_{\mathrm{p,m}} - T_{\mathrm{a}}\right)\right] \quad (1)$$

$$S = \eta_0 G \quad (2)$$

$$Q_{\mathrm{u}} = mc_{\mathrm{f}}\Delta T\eta = F_{\mathrm{R}}(\tau\alpha)_{\mathrm{e}} - F_{\mathrm{R}}U_{\mathrm{L}}T_{\mathrm{i}}^{*} \quad (3)$$

$$T_{\mathrm{i}}^{*} = \frac{T_{\mathrm{i}} - T_{\mathrm{a}}}{G} \quad (4)$$

Where, Q_u is the useful energy; S is the absorbed radiant energy, W/m^2; $T_{p,m}$, T_a The average temperature of the heat sink and the ambient temperature, K; η_0 is the absorption efficiency; c_f is the specific heat capacity, J/(kg.K); m is the mass flow of the working fluid, kg/s; ΔT is the temperature difference between the inlet and outlet; F_R is the thermal migration factor; $(\tau\alpha)_e$ is the product of the transmittance of the cover glass and the absorptivity of the heat sink; U_L is the total heat loss coefficient, $W/(m^2.k)$;η is the instantaneous efficiency; T_i^* is the normalized temperature difference, $(m^2.k)/W$;T_i is the temperature of the inlet and outlet working fluid, K;

Two-way ANOVA with interaction, which assumes that the combination of factor A and factor B will produce a new effect. For example, if it is assumed that consumers in different regions have different special preferences for a certain brand than consumers in other regions, this is a new effect generated by the combination of the two factors, which belongs to the background with interaction; otherwise, there is no interaction. background.

Two-factor univariate analysis of variance uses anova2 function p=anova2(X, reps), each column of matrix X corresponds to a level of factor A, and each row corresponds to a level of factor B, X should satisfy the basic assumption of variance analysis, reps mean. The number of groups of data for each level combination of factors A and B. The optimization method in this paper uses the two-factor univariate analysis of variance method with interactive effects. This method means that factor A and factor B have several levels respectively, and each level combination corresponds to several groups of data. Perform variance analysis on these data to obtain factor A. And factor B has a significant impact on the final result, and then analyze whether the interaction between the two has a significant impact on the final result.

Suppose factor A and factor B have r levels and s levels respectively, then there are A_1, A_2 … A_r and B_1, B_2 … B_s; It is assumed that the population (A_i, B_j) under the horizontal combination x_{ij} satisfies the normal distribution $N(\mu_{ij}, \sigma^2), i = 1, \cdots, r, j = 1, \cdots, s$, Let the horizontal combination (A_i, B_j) have t sets of data. The expression to change x_{ijk} to μ_{ij} and ε_{ijk} is as follows:

$$x_{ijk} = \mu_{ij} + \varepsilon_{ijk} \quad (5)$$
$$i = 1, \cdots, r, j = 1, \cdots, s, k = 1, \cdots, t$$

ε_{ijk} follows a normal distribution $N(0, \sigma^2)$ is independent of each other, Then we can get the overall mean μ, The effect of the level A_i of factor A on the final result a_i , The effect of the level B_i of factor B on the final outcome β_i and the interaction of A_i and B_i on the final outcome. The formula for calculating γ_{ij} is as follows:

$$\mu = \frac{1}{rs} \sum_{i=1}^{p} \sum_{j=1}^{s} \mu_{ij} \quad (6)$$

$$\mu_{i.} = \frac{1}{s} \sum_{j=1}^{s} \mu_{ij} \quad (7)$$

$$\alpha_i = \mu_{i.} - \mu \quad (8)$$

$$\mu_{.j} = \frac{1}{r} \sum_{i=1}^{r} \mu_{ij} \quad (9)$$

$$\beta_j = \mu_{\cdot j} - \mu \tag{10}$$

$$\gamma_{ij} = \mu_{ij} - \mu - \alpha_i - \beta_j \tag{11}$$

Then the mathematical model of the derived formula is:

$$x_{ijk} = \gamma_{ij} + \mu + \alpha_i + \beta_j + \varepsilon_{ijk} \tag{12}$$

$$\sum_{i=1}^{r}\alpha_i = 0, \sum_{j=1}^{s}\beta_j = 0, \sum_{i=1}^{r}\gamma_{ij} = \sum_{j=1}^{s}\gamma_{ij} = 0 \tag{13}$$

$$\varepsilon_{ijk} \sim N\left(0, \sigma^2\right) \tag{14}$$
$$i = 1, \cdots, r, \; j = 1, \cdots, s, k = 1, \cdots, t$$

Mainly based on the absorption rate of the heat sink plate of the collector α_p, The heat sink emissivity ε_p , The thickness of the heat sink δ_p, The thermal conductivity of the heat sink λ_p, The spacing of the pipes W, the inner diameter of the pipes D_i and the inlet temperature $T_{f,i}$ of the working medium in the exhaust pipe as the research focus to carry out a pairwise combination, Analyze whether the influence of the two factors alone and their interaction on the collector efficiency η is significant, and then obtain the optimal solution (the best combination of two key parameters).

The corresponding numerical calculation is carried out in python, and the variation of the thermal performance of the collector with the absorption rate, emissivity, thickness and thermal conductivity of the heat-absorbing plate is obtained as shown in

Figure 1.

It can be seen from

Figure 1 (a) that the absorption rate α_p has a significant effect on the useful energy Q_U and the instantaneous efficiency η, but has no significant effect on the total heat loss coefficient U_L, the fin efficiency F , the efficiency factor F' and the heat transfer factor F_R;

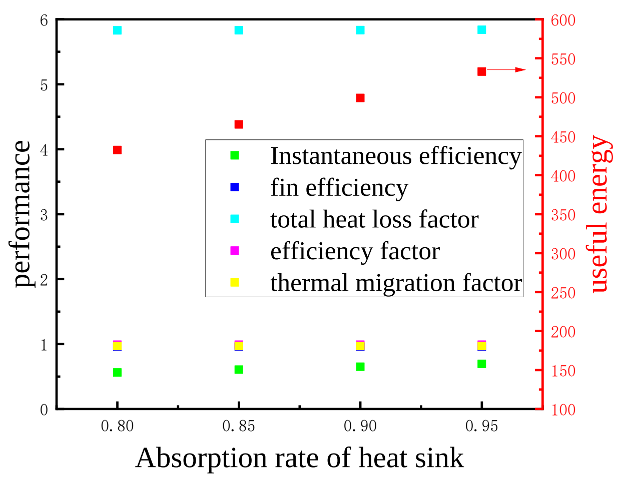
It can be seen from

Figure 1 (b) that the emissivity ε_p has no significant effect on the useful energy Q_U, the total heat loss coefficient U_L, the fin efficiency F , the efficiency factor F' and the thermal migration factor F_R ; the emissivity ε_p has a significant negative correlation effect on the instantaneous efficiency η ;

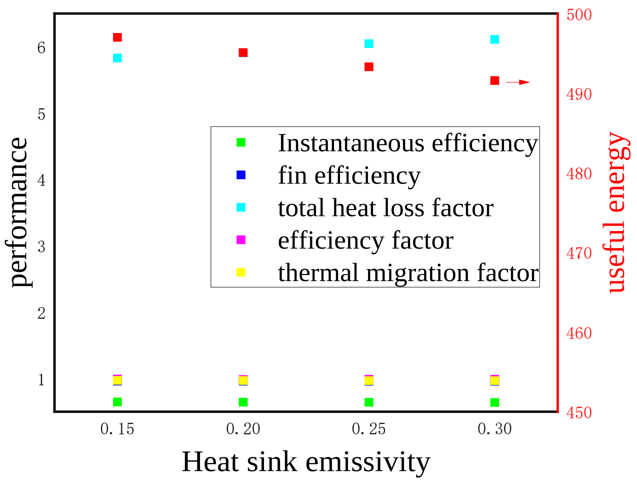
It can be seen from

Figure (c) that the thickness δ_p of the heat absorbing plate has a significant effect on the useful energy Q_U , the fin efficiency F , the efficiency factor F' , the heat transfer factor F_R and the instantaneous efficiency η, and has a certain degree of influence on the total heat loss coefficient U_L .

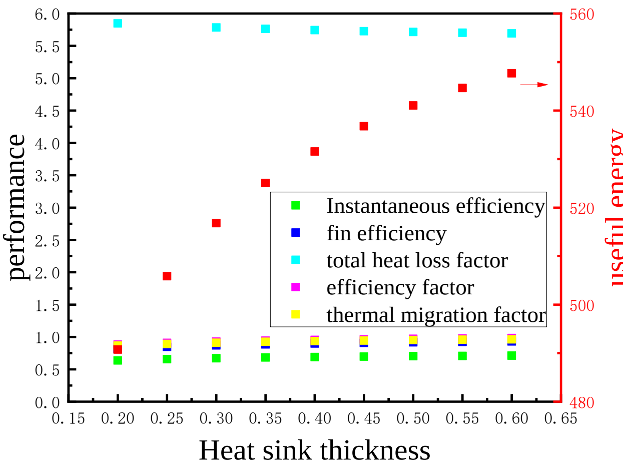
It can be seen from Figure 1 (d) that the thermal conductivity λ_p has a significant effect on the useful energy Q_U, the fin efficiency F , the efficiency factor F' , the heat transfer factor F_R and the instantaneous efficiency η, while the thermal conductivity λ_p has no significant effect on the total heat loss coefficient U_L.



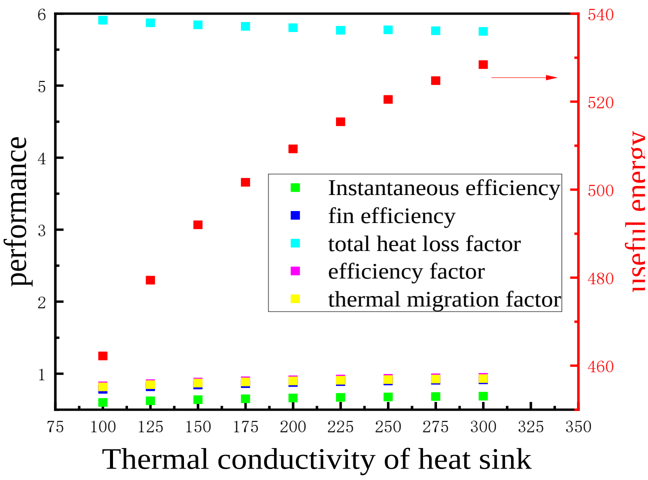
(a) Influence of surface absorptivity of heat absorbing plate on thermal performance of collector



(b) Influence of surface emissivity of heat absorbing plate on thermal performance of collector



(c) Influence of the thickness of the heat absorbing plate on the thermal performance of the collector



(d) Influence of thermal conductivity of heat sink plate on thermal performance of collector

Figure 1. Influence of key parameters of heat absorbing plate on the thermal performance of the collector

The corresponding numerical calculation is performed in python, and the thermal performance of the collector varies with the spacing of the tubes, the inner diameter of the tubes, and the inlet temperature of the working medium in the tubes, as shown in

Figure .

It can be seen from

Figure (e) that the spacing W of the rows of tubes has a negative correlation with the useful energy Q_U, and the spacing of the rows of tubes W has a positive correlation with the total heat loss coefficient U_L; The spacing of the tubes W has a significant effect on the fin efficiency F, the efficiency factor F', the heat transfer factor F_R and the instantaneous efficiency η.

It can be seen from

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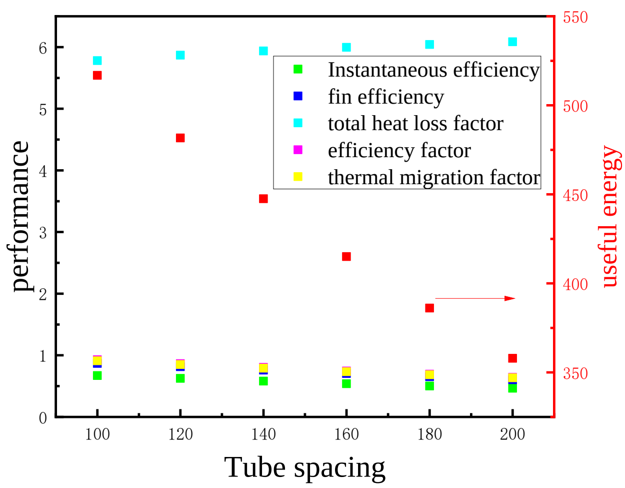
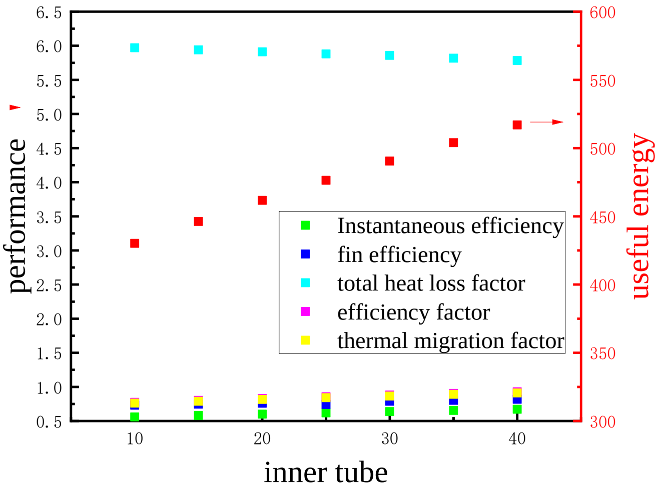
Figure (f) that the inner diameter D_i of the exhaust pipe has a significant effect on the useful energy Q_U, the fin efficiency F, the efficiency factor F', the heat transfer factor F_R and the instantaneous efficiency η; the inner diameter D_i of the exhaust pipe has almost no effect on the total heat loss coefficient U_L.

It can be seen from

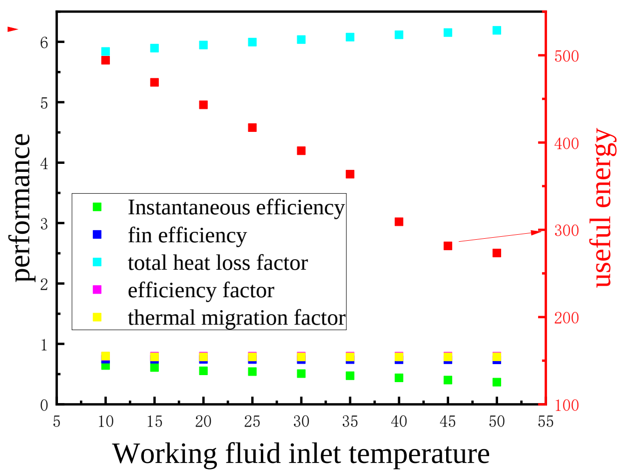
Figure (g) that the inlet temperature $T_{f,i}$ of the working medium in the exhaust pipe has a negative correlation effect on the useful energy Q_U and the instantaneous efficiency η, and the total heat loss coefficient U_L, the fin efficiency η, the efficiency factor F' and the heat transfer factor F_R are less affected by $T_{f,i}$.



(e) Influence of tube spacing on thermal performance of collector



(f) Influence of tube inner diameter on thermal performance of collector



(g) Influence of inlet temperature of working fluid in exhaust pipe on thermal performance of collector

Figure 2. Influence of key parameters of exhaust pipe on thermal performance of collector

Through the method of two-factor variance analysis, the absorptivity and thermal conductivity of the heat-absorbing plate of the collector, the thermal conductivity and thickness of the heat-absorbing plate of the collector, the absorptivity and the heat-absorbing plate of the heat-absorbing plate of the collector were analyzed. Numerical analysis was carried out on the interaction between the thickness, the distance between the heat collector tubes and the inner diameter of the tubes, the inner diameter of the collector tubes and the inlet temperature of the working medium in the tubes, and the distance between the collector tubes and the inlet temperature of the working medium in the tubes. Then the optimal combination can be obtained, and the purpose of optimizing the key parameters of the collector can be achieved.

1. Combined optimization of the absorption rate of the heat sink and the thermal conductivity of the heat sink. The value range of the absorption rate α_p of the heat sink plate of the collector is 0.80~0.95, which is set as Ap, that is, 0.80~0.95 is Ap1, Ap2, Ap3 and Ap4, respectively. The thermal conductivity λ_p of the heat sink is the thermal conductivity of the common materials of the heat sink: steel, iron, aluminum and copper: 36 W/m K, 80 $W/m.k$, 237 $W/m.k$ and 398 $W/m.k$, set λ_p as Tp, and the four thermal conductivity are respectively Tp1, Tp2, Tp3 and Tp4, which constitute 16 combinations.

According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the effect of the absorption rate of the heat sink plate of the collector and the thermal conductivity of the heat sink plate on the instantaneous efficiency η.

Table 1

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE ABSORPTION RATE OF THE HEAT SINK AND THE THERMAL CONDUCTIVITY OF THE HEAT SINK

parameter	*Tp1*	*Tp2*	*Tp3*	*Tp4*
Ap1	0.4166	0.4444	0.4721	0.4998
Ap2	0.5053	0.5407	0.576	0.6114
Ap3	0.594	0.6353	0.6766	0.7179
Ap3	0.6163	0.6593	0.7022	0.7452

According to the data in Table, the calculation program was written, and the calculated p values were 0.0000, 0.0154 and 0.0100, respectively, that is, the thermal conductivity of the heat sink, the absorption rate of the heat sink and the interaction of the two had significant effects on the instantaneous efficiency η. Through further analysis of the interaction, it was found that the mean value of the combination 'Ap4, Tp4' was the highest, that is, the mean value of the combination '0.95, 398 $W/m.k$' was 0.7452.

2. Combined optimization of thermal conductivity of heat sink and thickness of heat sink. The values of the thermal conductivity of the hot plate are the thermal conductivity of iron, aluminum and copper, which are common materials of the heat sink: 80 $W/m.k$, 237 $W/m.k$ and 398 $W/m.k$, respectively. The thickness δ_p of the heat absorbing plate can be varied in the range of 0.2…0.6 mm. By setting λ_p and δ_p as Tp and Ep respectively, there are 15 combinations. According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the influence of the thickness of the heat-absorbing plate of the collector and the thermal conductivity of the heat-absorbing plate on the instantaneous efficiency η. As shown in Table 2.

According to the data in Table 2, the calculation program was written, and the p-values obtained from the simulation were 0.0000, 0.0201 and 0.0000, respectively, that is, the thermal conductivity of the heat sink, the thickness of the heat sink and the interaction of the two had significant effects on the instantaneous efficiency η. Through further analysis of the interaction, it was found that the mean of the combination 'Ep5, Tp3' was the highest, that is, the mean of the combination '0.6, 398 $W/m.k$ ' was 0.7215.

Table 2

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE THERMAL CONDUCTIVITY OF THE HEAT SINK AND THE THICKNESS OF THE HEAT SINK

parameter	*Tp1*	*Tp2*	*Tp3*
Ep1	0.5251	0.6494	0.6795
Ep2	0.5754	0.6776	0.6995
Ep3	0.607	0.693	0.7103
Ep4	0.6286	0.7026	0.7169
Ep5	0.6444	0.7092	0.7215

3. Combined optimization of heat sink absorption rate and heat sink thickness. The value range of the absorption rate α_p of the heat absorbing plate of the collector is 0.80~0.95, and the value range of the thickness δ_p of the heat absorbing plate is 0.20~0.60mm. If α_p and δ_p are set to Ap and Ep, respectively, there are 20 combinations. According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the effect of the collector absorption rate and the thickness of the heat absorbing plate on the instantaneous efficiency η. As shown in Table 3.

Table 3

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE ABSORPTION RATE OF THE HEAT SINK AND THE THICKNESS OF THE HEAT SINK

parameter	*Ap1*	*Ap2*	*Ap3*	*Ap4*
Ep1	0.5954	0.6372	0.6789	0.7207
Ep2	0.6133	0.6563	0.6992	0.7423
Ep3	0.6228	0.6665	0.7101	0.7538
Ep4	0.6287	0.6728	0.7168	0.7609
Ep5	0.6228	0.6771	0.7214	0.5657

According to the data, the calculation program was written, and the calculated p values were 0.0000, 0.0000 and 0.0100 respectively, that is, the absorption rate of the heat sink, the thickness of the heat sink and the interaction of the two had significant effects on the instantaneous efficiency η. Through a one-step analysis of the interaction, that is, the combination of '0.50mm, 0.95' obtains the best mean value of instantaneous efficiency of 0.7609.

4. Combination optimization of tube spacing and tube inner diameter. The value range of the collector tube spacing W is 100~200 mm, and the variation range of the tube inner diameter D_i is 10mm~40mm. Set W and D_i as W and DI, respectively, there are 24 combinations. According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the influence of the distance between the collector tubes and the inner diameter of the tube on the instantaneous efficiency η. As shown in According to the data in Table 4, the calculation program was written to obtain p values of 0.0178, 0.0253 and 0.0018, respectively, that is, the inner diameter of the tube, the distance between the tubes, and the interaction between the tube spacing and the inner diameter of the tube have significant effects on the instantaneous efficiency η. Through further analysis of the interaction, it is found that the mean value

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of the combination 'W1, DI4' is the highest, that is, the mean value of the combination '100 mm, 40 mm' is 0.8643.

Table 4According to the data in Table 4, the calculation program was written to obtain p values of 0.0178, 0.0253 and 0.0018, respectively, that is, the inner diameter of the tube, the distance between the tubes, and the interaction between the tube spacing and the inner diameter of the tube have significant effects on the instantaneous efficiency η. Through further analysis of the interaction, it is found that the mean value of the combination 'W1, DI4' is the highest, that is, the mean value of the combination '100 mm, 40 mm' is 0.8643.

Table 4

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE SPACING OF THE TUBES AND THE INNER DIAMETER OF THE TUBES

parameter	*DI1*	*DI2*	*DI3*	*DI4*
W1	0.7874	0.8144	0.8387	0.8643
W2	0.7674	0.7844	0.8054	0.8225
W3	0.7481	0.7633	0.7769	0.7896
W4	0.7288	0.7405	0.7505	0.7601
W5	0.7114	0.7221	0.7306	0.7392
W6	0.6912	0.6998	0.7057	0.7121

5. Combination optimization of the inner diameter of the exhaust pipe and the inlet temperature of the working medium in the exhaust pipe. The variation range of the inner diameter D_i of the exhaust pipe is 10~40mm, and the variation range of the inlet temperature $T_{f,i}$ of the working medium in the exhaust pipe is 10~50°C. Set D_i and $T_{f,i}$ as DI and TFI respectively, there are 36 combinations. According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the influence of the inner diameter of the collector tube and the inlet temperature of the working medium in the tube on the instantaneous efficiency η. As shown in Table.

Table5

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE INNER DIAMETER OF THE TUBE AND THE INLET TEMPERATURE OF THE WORKING MEDIUM IN THE TUBE

parameter	*TFI1*	*TFI2*	*TFI3*
DI1	0.8094	0.7716	0.7329
DI2	0.8333	0.7952	0.7554
DI3	0.8557	0.817	0.7762
DI4	0.8723	0.8337	0.7925
parameter	*TFI4*	*TFI5*	*TFI6*
DI1	0.693	0.6524	0.6109
DI2	0.7144	0.6726	0.6301
DI3	0.7341	0.6912	0.6475
DI4	0.7499	0.7063	0.662
parameter	*TFI7*	*TFI8*	*TFI9*
DI1	0.569	0.5265	0.4834
DI2	0.5869	0.5432	0.4988
DI3	0.6032	0.5581	0.5126
DI4	0.6169	0.5713	0.525

According to the data in Table, a simulation program was written, and the p values were 0.0178, 0.0098 and 0.0018, respectively, that is, the inner diameter of the exhaust pipe, the inlet temperature of the working medium in the exhaust pipe, and the interaction between the inner diameter of the exhaust pipe and the inlet temperature of the working medium in the exhaust pipe affect the instantaneous efficiency. The effect of η is significant. Through further analysis of the interaction, it was found that the combination 'DI4, TFI1' had the highest mean value, that is, the mean value of the combination '40 mm, 10°C' was 0.8723.

6. Combination optimization of the spacing between the tubes and the inlet temperature of the working medium in the tubes. The variation range of the tube spacing W is 100~200mm, and the variation range of the inlet temperature $T_{f,i}$ of the working medium in the tube is 10~50°C. Set W and $T_{f,i}$ to be W and TFI respectively, there are 54 combinations in total. According to the python calculation program, simulate the program four times to obtain an average instantaneous efficiency result, and obtain a data table of the effect of the distance between the collector tubes and the inlet temperature of the working medium in the tube on the instantaneous efficiency η. As shown in Table .

Table 6

THE INSTANTANEOUS EFFICIENCY OF THE COLLECTOR VARIES WITH THE SPACING OF THE TUBES AND THE INLET TEMPERATURE OF THE WORKING MEDIUM IN THE TUBES

parameter	*TFI1*	*TFI2*	*TFI3*
W1	0.8789	0.8402	0.7985
W2	0.855	0.8164	0.7757
W3	0.8324	0.7942	0.7544
W4	0.81	0.7725	0.7336
W5	0.7918	0.7546	0.7163
W6	0.7694	0.7329	0.6955
parameter	*TFI4*	*TFI5*	*TFI6*
W1	0.7555	0.7116	0.6668
W2	0.7338	0.691	0.6474
W3	0.7135	0.6718	0.6293
W4	0.6936	0.653	0.6116
W5	0.6771	0.6372	0.5967
W6	0.6572	0.6183	0.5788
parameter	*TFI7*	*TFI8*	*TFI9*
W1	0.6213	0.5752	0.5285
W2	0.6031	0.5582	0.5127
W3	0.5862	0.5424	0.4982
W4	0.5696	0.5271	0.484
W5	0.5556	0.514	0.4719
W6	0.5389	0.4985	0.4575

According to the data in Table , the calculation program was written, and the calculated p values were 0.0000, 0.0098 and 0.0000 respectively, that is, the influence of the inner diameter of the exhaust pipe on the instantaneous efficiency was not significant, but the inlet temperature of the working medium in the exhaust pipe, the inner diameter of the exhaust pipe and the inlet of the working medium in the exhaust pipe were not significant. The interaction of temperature has a significant effect on the instantaneous efficiency η. Through further analysis of the interaction, it was found that the mean value of the combination 'W1, TFI1' was the highest, that is, the mean value of the combination '100 mm, 10°C' was 0.8789.

A mathematical model for the performance calculation of flat-panel solar collectors was established through PYTHON. Through the calculation and analysis of the data, the influence of the key parameters of the collector on the instantaneous efficiency of the collector was obtained. 0.95), an increase of 23.68%; a decrease of 1.09% under the change range of the heat sink emissivity (0.15-0.30); an increase of 12.25% under the heat sink thickness change range (0.20-0.60); The coefficient variation range (100-300) increased by 14.31%; the tube spacing variation range (100-200) decreased by 30.75%; the tube inner diameter variation range (10-40) increased by 20.18%; The inlet temperature of the working fluid in the tube decreases by 43.05% under the variation range (10-50);

Using the two-factor analysis method, a two-factor one-way variance analysis mathematical model with interactive effects was established to analyze and optimize the key parameters of the collector's own structure, and finally the optimization results were obtained:

1. The best combination of absorption rate and thermal conductivity of the heat-absorbing plate, that is, the combination of '0.95, 398 $W/m.k$'.
2. The best combination of thermal conductivity of the heat sink and thickness of the heat sink, that is, the combination of '0.6 mm, 398 $W/m.k$'.
3. The best combination of absorption rate and thickness of the heat absorbing plate, that is, the combination of '0.50mm, 0.95'.
4. The best combination of tube spacing, and tube inner diameter is the combination of '100mm, 40mm'.
5. The best combination of the inner diameter of the exhaust pipe and the inlet temperature of the working medium in the exhaust pipe is the combination of '40 mm, 10°C'.
6. The best combination of the spacing between the tubes and the inlet temperature of the working medium in the tubes is the combination of '100 mm, 10°C'.

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