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Analysis of the effect of transparent covers on receiver of cylindrical parabolic solar collectors

Silindirik parabolik güneş toplayıcılarda alıcı üzerine uygulanan saydam örtünün etkisinin analizi

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Analysis of The Effect of Transparent Covers on Receiver of Cylindrical Parabolic Solar Collectors

Highlights

- *Parabolic solar collectors are preferred because of their high efficiency.*
- *Parabolic solar collectors with initial investment costsstands out.*
- *The effect of the second glass on the collector pipe on the efficiency increase of the cylindrical parabolic collector.*
- *At fluid temperatures between 0–500 Kelvin, the second layer is not more efficient than the one-layer system, and at 500–700 Kelvin, the efficiency of the double-layer system increases.*

Graphical Abstract

In order to increase the efficiency of cylindrical parabolic glass collectors, a second glass was designed on the collector pipe and its effect on the efficiency was investigated.

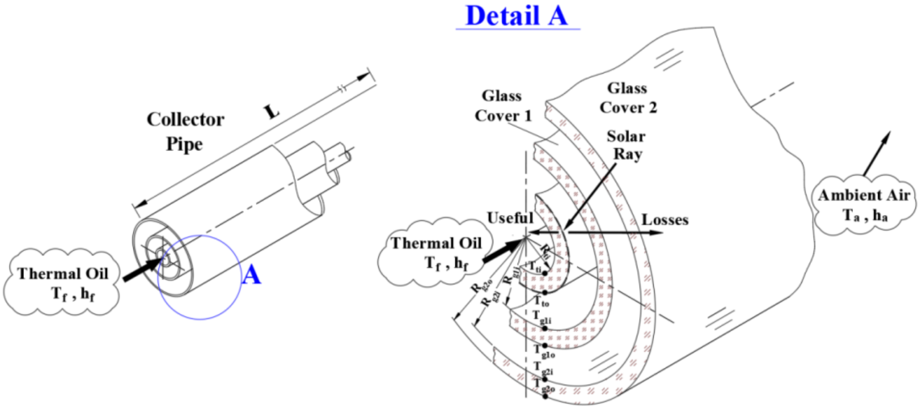

Figure. Heat transfer to the fluid through parallel cylindrical walls; cross-sectional demonstration of collector tube and glass cover

Aim

In order to increase efficiency in cylindrical parabolic glass collectors, the effect of the second glass layer on the collector pipe on the system efficiency was investigated.

Design & Methodology

A second glass layer was added on the collector pipe of the cylindrical parabolic glass collectors. The effect of this glass layer is solved using heat transfer and thermodynamic equations.

Originality

It is an original study on increasing efficiency in cylindrical parabolic glass collectors.

Findings

Double-layer Parabolic glass solar collectors did not have much effect on system efficiency at 0–500 Kelvin fluid temperatures. It has been determined that the double layer system has an effect on efficiency at temperatures of 500–700 Kelvin.

Conclusion

Results of calculations show that the two-cover system is not more efficient than the single cover system at low fluid temperatures between 0 and 500 K and the efficiency of the two-cover system is increased at medium fluid temperatures between 500 and 700 K.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Silindirik Parabolik Güneş Toplayıcılarda Alıcı Üzerine Uygulanan Saydam Örtünün Etkisinin Analizi

Araştırma Makalesi / Research Article

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ÖZ

Parabolik güneş toplayıcıları yüksek verimleri sebebiyle tercih edilmekte, diğer uygulamalara göre düşük işletme ve ilk yatırım maliyetleri ile silindirik parabolik güneş toplayıcıları ön plana çıkmaktadır. Bu çalışmada, silindirik parabolik güneş toplayıcılarının veriminin artırılmasına yönelik toplayıcı boru üzerine ikinci cam katmanı uygulamasının etkileri incelenecektir. Bu şekilde kayıpların azaltılarak verimin artması öngörülmüştür. Kayıpların ve anlık verimin değişimini inceleyebilmek için parabolik oluk kollektör sistemini oluşturan yapının tüm parametreleri, optik kayıplar, malzeme özellikleri ve dış ortam iklim şartları dikkate alınarak bir model oluşturulmuş, gerekli hesaplamalar yapılarak sonuçları değerlendirilmiştir. Çalışmanın sonucunda 0–500 K arasındaki düşük akışkan sıcaklıklarında ikinci katmanın bir katmanlı sisteme göre daha verimli olmadığı, 500–700 K arasındaki orta akışkan sıcaklıklarında ise çift katmanlı sistemin veriminin yükseldiği görülmüştür.

Anahtar Kelimeler: Güneş enerjisi, parabolik güneş kollektörleri, yenilenebilir enerji kaynakları.

Analysis of the Effect of Transparent Covers on Receiver of Cylindrical Parabolic Solar Collectors

ABSTRACT

Parabolic solar collectors with central receiving systems are preferred due to their high efficiency despite their high initial investment and operating costs. In this study, the effect of two glass covers on tubular collector will be investigated, aiming enhancement of cylindrical parabolic solar collectors' efficiency. By using glass cover it is aimed to decrease losses and increase efficiency. In order to investigate the changes of losses and instantaneous efficiency, a model was constructed considering all parameters of the structure, optical losses, material properties and outdoor climatic conditions. Results of calculations show that the two-cover system is not more efficient than the single cover system at low fluid temperatures between 0 and 500 K and the efficiency of the two-cover system is increased at medium fluid temperatures between 500 and 700 K.

Keywords: Parabolic solar collectors, efficiency of collectors, solar energy, renewable energy sources

1. INTRODUCTION

Difficulty in accessing energy sources, high energy prices and environmental pollution increase the interest in renewable energy sources. One of the most popular research topics in renewable energy field is the solar energy. Different system configurations are used in the literature for the use of solar energy. Flat plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic bowl, and heliostat field collectors are among the types encountered in practice [1].

Although rarely used, parabolic solar collector systems are more appropriate for some electricity generation applications by using heat energy. Parabolic solar collectors with central receiving system are proven systems due to their high efficiency despite initial investment costs and high operating costs [2]. In these systems, at the centre of the parabolic shaped concentrators, the tubes with the absorber surface are added together to form series. The inner side of the concentrators are reflective surfaces. Reflected light is concentrated on the linear absorber tube at the centre. Concentrating systems are capable of producing enormously hot fluid for a variety of processes, and they can produce relatively large amount of energy for each dollar invested. However, these systems tend to be much larger and more complex than the other types of solar collectors. Thus, concentrating solar technology tends to be most effective for large-scale, high-temperature uses, although lower-temperature uses may still be cost-effective under certain circumstances [3]. Solar tracking systems also increases the solar collector's efficiency. The heat energy obtained by the fluid in the absorbent pipe is first converted to the steam and then electricity in the power plant. While water, oil and organic compounds are generally used as heat transfer fluid up to 400°C [4], it is possible to rise above 500°C with molten salt [5]. In recent studies, parabolic systems which can work at low temperatures and mirror surfaces with photovoltaic

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batteries are being studied so that water is more convenient as a heat transfer fluid. Since this technology has high concentration rate, it is possible to obtain steam at a temperature range of 350°C to 400°C on the power plant side. In order to produce 1 MW energy, an average cost of 5 million Euro and for solar farming 35 acres are needed. Many applications of the linear concentrator technology is used commercially [6].

Some of the energy of the solar rays falling on the collectors are absorbed by the collector surface. This part, called receiver, is the part that determines the efficiency of the parabolic trough collector system with its optical and thermal properties [7]. The energy that surface absorbes is transferred to the fluid by conduction and convection. Energy that can not be absorbed by the collector is transferred to the atmosphere by convection proportional to collector temperature and convection coefficient. The difference between the energy absorbed and the energy transferred to the atmosphere is the useful solar energy, which is desired to be transferred to the fluid.

Transparent cover is used to reduce heat losses. Heat losses due to convection increase especially with increasing air movements and heat transfer coefficient between the absorbing surface and atmosphere is reduced by using a transparent cover. Thus, useful radiation is increased. The transparent cover increases resistance to heat loss as well as prevents absorbing surface from negative weather conditions (such as rain and dirt). In order to reduce heat losses, heat conduction resistance can be increase by applying vacuum between the transparent coating and the receiving surface [8]. The applied vacuum reduces heat losses and protects the receiver surface coating [9]. It is also possible to reduce heat losses by increasing the loss resistance by using transparent insulation materials between the glass coating and the receiver surface [10] to increase the receiver efficiency, by using internal radiation shields [11] or by making a part of the upper ring with a different material [12].

Transparent covers, which can transmit sun rays with short wavelength better and which does not transmit sun rays with long wavelength reflected by receiving surface of collector, are preferred. On the other hand, withstanding capacity to high temperature conditions, machinability and cost are important properties for transparent covers. Also withstanding capacity against ultraviolet radiation, negative weather conditions such as hail falls, physical resistance in case of a falling stone or public vandalism can be important issues to be considered during cover selection [13].

Objects called semi-transparent, reflect some of the light, absorbs some other part and transmit the rest. The light is emitted in various wave lengths. The sum of the ratios for reflection (ρ), absorption (α) and transmition (τ) is equal to one for a wavelength.

$$\alpha + \rho + \tau = 1 \tag{1}$$

1.1. Thermal Analysis

Collector tubes are desired to absorb a large portion of the concentrated rays. Therefore, the collector tubes are coated with selective materials which have low reflectivity, for example molybdenum and silicon nitride ($Mo\text{-}Si_3N_4$) [14]. These materials absorb almost all of the short wavelength rays, while emit long wavelength rays. They are coated with spraying method, electrolysis coating and chemical bath coating [15]. The use of nanofluids such as TiO_2/DI-H_2O (De-Ionized water) [16] and Cu nanoparticles in thermal oil [17] to increase the efficiency of heat transfer to the thermal fluid.

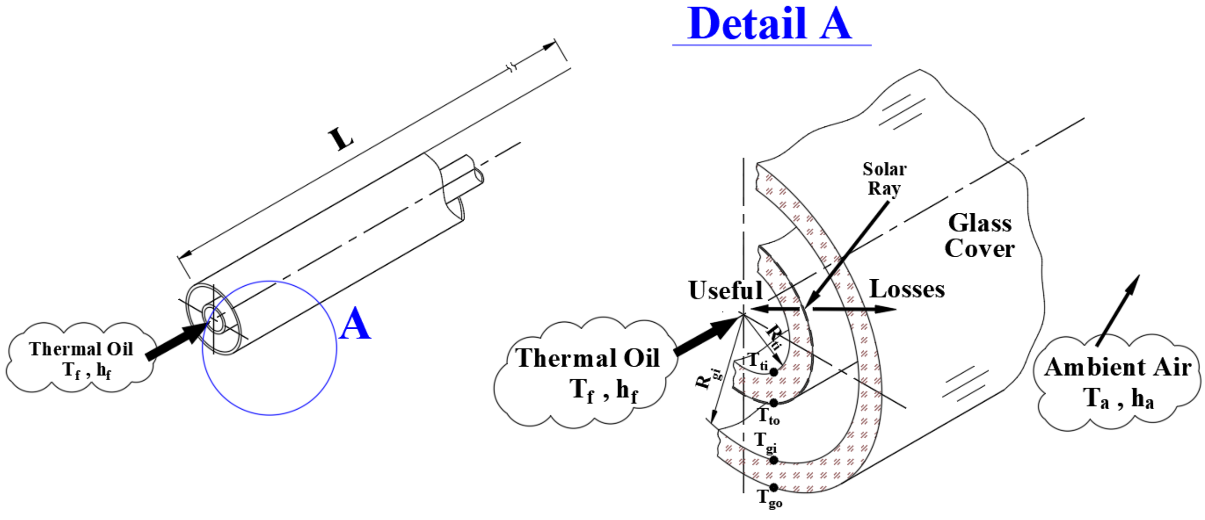

Figure 1. Heat transfer to the fluid through parallel cylindrical walls; cross-sectional demonstration of collector tube and glass cover

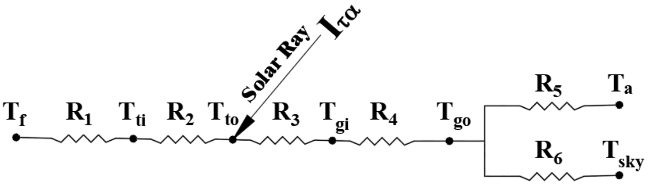

Figure 2. Thermal circuit for collector tube and one glass cover

Because of the parabolic reflector geometry, higher temperatures, and irregular scattering of light on the collector surface, thermal analysis of parabolic collectors is more complicated (but similar) than that of flat ones. It is necessary to consider all the important heat fluxes in order to provide energy balance. The non-linear thermal equilibrium equations are solved by iterative approaches. In this study, calculations were made according to the mathematical model developed by considering the collector tube as an open tube [18].

In Figure 1 and 2; R_1 represents the thermal convection resistance from receiving tube to the oil, R_2 represents the conduction resistance of the tube, R_3 represents radiation resistance of the vacuum between the tube and transparent cover, R_4 represents conduction resistance of transparent (glass) tube, R_5 represents convection resistance of the glass tube and atmosphere, R_6 represents radiation resistance of glass tube. These are formulated as;

$$R_1 = \frac{1}{2\cdot\pi\cdot r_{ti}\cdot L\cdot h_f} \tag{2}$$

$$R_2 = \frac{1}{2\cdot\pi\cdot L\cdot k_t}\cdot \ln\left(\frac{r_{to}}{r_{ti}}\right) \tag{3}$$

$$R_3 = \frac{\left[\frac{1}{\varepsilon_t} + \frac{1-\varepsilon_g}{\varepsilon_g}\cdot\left(\frac{r_{to}}{r_{gi}}\right)\right]}{2\cdot\pi\cdot L\cdot\sigma\cdot r_{to}\cdot\left[\left(T_{to}^2+T_{gi}^2\right)\cdot\left(T_{to}+T_{gi}\right)\right]} \tag{4}$$

$$R_4 = \frac{1}{2\cdot\pi\cdot L\cdot k_g}\cdot \ln\left(\frac{r_{go}}{r_{gi}}\right) \tag{5}$$

$$R_5 = \frac{1}{2\cdot\pi\cdot r_{go}\cdot L\cdot h_a} \tag{6}$$

$$R_6 = \frac{1}{2\cdot\pi\cdot\varepsilon\cdot\sigma\cdot r_{go}\cdot L\cdot\left[\left(T_{go}^2+T_{sky}^2\right)\cdot\left(T_{sky}+T_{go}\right)\right]} \tag{7}$$

Energy equilibrium equation for Figure 2 can be written as;

$$E_{input} = E_{fluid} + E_{lost} \tag{8}$$

$$I\cdot\alpha\cdot\tau\cdot\pi\cdot d_{to} = \frac{T_{to}-T_f}{R_1+R_2} + \frac{T_{to}-T_{sky}}{R_3+R_4+\left(R_5^{-1}+R_6^{-1}\right)^{-1}} \tag{9}$$

This energy equilibrium equation for parabolic collectors with concentrator also represents useful energy transferred from the collector tube to the fluid by convection.

By using mean temperature definition and perfect gas assumption, energy equilibrium for a differential control volume can be written as;

$$dq_f = \dot{m}\cdot c_p\cdot dT_f \tag{10}$$

where $\dot{m}$ is the mass flow rate.

This relation can also be used for incompressible liquids with great accuracy. Integration from the i inlet to the o outlet of tube results;

$$q_f = \dot{m}\cdot c_p\cdot\left(T_{f,o}-T_{f,i}\right) \tag{11}$$

where q_f is the total heat transferred from the pipe. This basic energy equation is related with three important heat parameters; (q_f , $T_{f,o}$, $T_{f,i}$)

Equation 10 can be written as;

$$\dot{m}\cdot c_p\cdot\frac{dT_f}{dx} = \frac{T_{to}-T_f}{R_1+R_2} \tag{12}$$

which has two unknown parameters T_f and T_{to}.

Efficiencies of the system for the first and second laws of thermodynamics [19] are given as;

$$\eta_I = \frac{E_{useful}}{E_{total}} = \frac{\dot{m}\cdot c_f\cdot\left(T_{f,i}-T_{f,o}\right)}{a\cdot L\cdot I} \tag{13}$$

$$\eta_{II} = \frac{\dot{m}\cdot c_f\cdot\left[\left(T_{f,o}-T_{f,i}\right)-T_{sky}\ln\left(\frac{T_{f,o}}{T_{f,g}}\right)\right]}{a\cdot L\cdot I_{local}\cdot\left[1-\frac{4T_{sky}}{3T_s}\right]} \tag{14}$$

where Ts is the blackbody temperature of the sun with a value of 5762 K [3].

In the case of two transparent cover; cross-section of collector and thermal resistance diagram are given in Figure 3 and Figure 4, respectively;

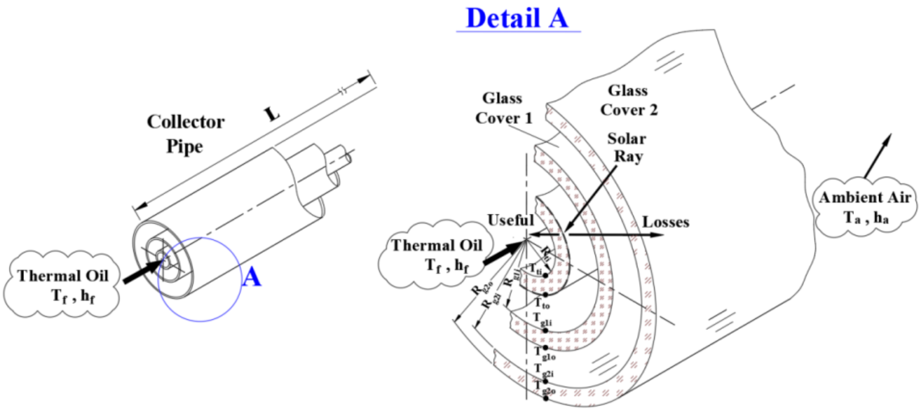

Figure 3: Heat transfer to the fluid through parallel cylindrical walls; cross-sectional demonstration of collector tube and two glass covers

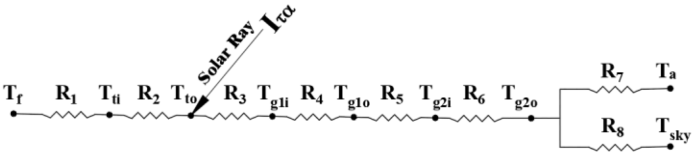

Figure 4: Thermal circuit for collector tube and two glass covers

Different from the single transparent cover case;

R_5 represents radiation resistance of the vacuum between the glass tubes and R_6 represents conduction resistance of the second glass tube. These are formulated as;

$$R_5 = \frac{\left[\frac{1}{\varepsilon_{g1}} + \frac{1-\varepsilon_{g2}}{\varepsilon_{g2}}\cdot\left(\frac{r_{g1o}}{r_{g2i}}\right)\right]}{2\cdot\pi\cdot L\cdot\sigma\cdot r_{g1o}\cdot\left[\left(T_{g1o}^2+T_{g2i}^2\right)\cdot\left(T_{g1o}+T_{g2i}\right)\right]} \tag{15}$$

$$R_6 = \frac{1}{2\cdot\pi\cdot L\cdot k_{g2}}\cdot\ln\left(\frac{r_{g2o}}{r_{g2i}}\right) \tag{16}$$

Energy Equation for Figure 4;

$$I\cdot\alpha\cdot\tau\cdot\pi\cdot d_{to} = \frac{T_{to}-T_f}{R_1+R_2} + \frac{T_{to}-T_{sky}}{R_3+R_4+R_5+R_6+\left(R_7^{-1}+R_8^{-1}\right)^{-1}} \tag{17}$$

This energy equilibrium equation for parabolic collectors with concentrator also represents useful energy transferred from the collector tube to the fluid by convection.

2. MATERIALS AND METHOD

In this study, the temperature changes of the fluid in the parabolic channel collector with a one-axis solar tracking system will be calculated for constant radiation and time-independent conditions. By these calculations we will observe the effect of transparent cover number and dimension on fluid temperature. For this purpose, collector pipe surface temperature, fluid temperature and transparent cover temperature will be calculated for single and two transparent covers at different diameters.

From the mathematical model given above, equations used in calculation of fluid temperature, receiving surface temperature and transparent cover temperature for a single transparent cover and equations used for calculation of fluid temperature, receiving surface temperature and transparent cover temperature for a collector with two transparent cover will be determined. Calculations are made for specific physical properties and results are shown on graphs.

2.1. Heat Transfer Equations for Single Transparent Cover Case

The inlet and outlet temperatures of the thermal oil and the surface temperature of the collector pipe should be calculated to determine the efficiency values. For this, calculations will be done by iterative method using equations above. The differential Equation 12;

$$\dot{m}\cdot c_p\cdot\frac{dT_f}{dx} = \frac{T_{to}-T_f}{R_1+R_2} \tag{18}$$

where R_2 , conduction resistance of the pipe can be neglected as it is so small relative to the other resistance values. By this elimination it can be rewritten as;

$$\dot{m}\cdot c_p\cdot\frac{dT_f}{dx} = \frac{T_{to}-T_f}{R_1} \tag{19}$$

and Fourier expansion of the equation is;

$$\dot{m}\cdot c_p\cdot\frac{T_{f,i+1}-T_{f,i}}{\Delta x} = \frac{T_{t,i}-T_{f,i}}{R_1} \tag{20}$$

By this equation; with the assumption of constant heat flux from the pipe surface, fluid temperature gradient along the flow direction can be calculated for given initial fluid temperatures.

$$T_{f,i+1} = \frac{T_{t,i}-T_{f,i}}{R_1}\cdot\frac{\Delta x}{\dot{m}\cdot c_p} + T_{f,i} \tag{21}$$

Similarly, if the conduction resistances R_2 and R_4 are neglected;

$$T_{to} = \left[\left(I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} \right) - \frac{T_{to} - T_{sky}}{R_3 + \left(R_5^{-1} + R_6^{-1} \right)^{-1}} \right] \cdot R_1 + T_f \tag{22}$$

The transparent cover temperature can be calculated by iteration;

$$E_{lost} = \frac{\Delta T}{R_{total}} = \frac{T_{to} - T_{sky}}{R_3 + R_4 + \left(R_5^{-1} + R_6^{-1} \right)^{-1}} = \frac{T_{to} - T_{gi}}{R_3} \tag{23}$$

and by eliminating conduction resistance;

$$E_{lost} = \frac{T_{to} - T_{sky}}{R_3 + \left(R_5^{-1} + R_6^{-1} \right)^{-1}} = \frac{T_{to} - T_{gi}}{R_3} \tag{24}$$

Thus the inner and outer surface temperatures of the transparent cover can be assumed as equal;

$$T_{gi} = T_{go} = T_g \tag{25}$$

R_3 and R_6 resistances are;

$$R_3 = \frac{\dfrac{1}{\varepsilon_t} + \left(\dfrac{1 - \varepsilon_g}{\varepsilon_g} \cdot \dfrac{r_{to}}{r_{gi}} \right)}{2 \cdot \pi \cdot L \cdot \sigma \cdot r_{to} \cdot \left[\left(T_{to}^2 + T_g^2 \right) \cdot \left(T_{to} + T_g \right) \right]} \tag{26}$$

$$R_6 = \frac{1}{2 \cdot \pi \cdot \varepsilon \cdot \sigma \cdot r_{go} \cdot L \cdot \left[\left(T_g^2 + T_{sky}^2 \right) \cdot \left(T_{sky} + T_g \right) \right]} \tag{27}$$

and by iteration;

$$T_g = T_{to} - \left[\frac{T_{to} - T_{sky}}{R_3 + \left(R_5^{-1} + R_6^{-1} \right)^{-1}} \right] \cdot R_3 \tag{28}$$

2.2. Heat Transfer Equations for Double Transparent Covers Case

Similar to the one transparent cover case, Fourier Expansion is done as;

$$T_{f,i+1} = \frac{T_{t,i} - T_{f,i}}{R_1} \cdot \frac{\Delta x}{\dot{m} c_p} + T_{f,i} \tag{29}$$

As it can be seen energy gained is same as in the transparent cover case. However the losses are different;

$$I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} = \frac{T_{to} - T_f}{R_1 + R_2} + \frac{T_{to} - T_{sky}}{R_3 + R_4 + R_5 + R_6 + \left(R_7^{-1} + R_8^{-1} \right)^{-1}} \tag{30}$$

R_2 , R_4 and R_6 can be neglected as they are so small relative to the other resistance values, energy equilibrium equation can be rewritten as;

$$I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} = \frac{T_{to} - T_f}{R_1} + \frac{T_{to} - T_{sky}}{R_3 + R_5 + \left(R_7^{-1} + R_8^{-1} \right)^{-1}} \tag{31}$$

Than surface temperature is;

$$T_{to} = \left[\left(I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} \right) - \frac{T_{to} - T_{sky}}{R_3 + R_5 + \left(R_7^{-1} + R_8^{-1} \right)^{-1}} \right] \cdot R_1 + T_f \tag{32}$$

If initial transparent cover temperature is given the other values can be calculated. Similar to the surface temperature calculation, conduction resistances are neglected and;

$$E_{lost} = \frac{\Delta T}{R_{total}} = \frac{T_{to} - T_{sky}}{R_3 + R_5 + \left(R_7^{-1} + R_8^{-1} \right)^{-1}} = \frac{T_{to} - T_{g1i}}{R_3} \tag{33}$$

$$I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} = \frac{T_{to} - T_f}{R_1} + \frac{T_{to} - T_{g1i}}{R_3} \tag{34}$$

By iteration;

$$T_{g1i} = T_{to} - \left[\left(I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} \right) - \frac{T_{to} - T_f}{R_1} \right] \cdot R_3 \tag{35}$$

By assuming glass surface temperatures are equal;

$$T_{g1i} = T_{g1o} = T_{g1} \tag{36}$$

and lost energy is;

$$E_{lost} = \frac{\Delta T}{R_{total}} = \frac{T_{to} - T_{sky}}{R_3 + R_5 + \left(R_7^{-1} + R_8^{-1} \right)^{-1}} = \frac{T_{to} - T_{g2i}}{R_3 + R_5} \tag{37}$$

By iteration;

$$T_{g2i} = T_{to} - \left[\left(I \cdot \alpha \cdot \tau \cdot \pi \cdot d_{to} \right) - \frac{T_{to} - T_f}{R_1} \right] \cdot \left(R_3 + R_5 \right) \tag{38}$$

To calculate heat transfer in inner and outer flow for turbulence Dittlus – Boelter correlation is used;

$$Nu = 0.023 * Re^{0.8} * Pr^{\frac{1}{3}} \tag{39}$$

where;

$$Nu = h.\frac{d_p}{k_f} \tag{40}$$

$$Re = \frac{4.m}{\mu.d.\pi} \tag{41}$$

Correlation for all Re and Pr numbers [20]; Nu number for convection between outer surface of the glass and atmosphere is given as:

$$\overline{Nu}_D = 0.3 + \frac{0.62 \cdot Re_D^{1/2} \cdot Pr^{1/3}}{\left[1 + (0.4 / Pr)^{2/3} \right]^{1/4}} \left[1 + \left(\frac{Re_D}{282000} \right)^{5/8} \right]^{4/5} \tag{42}$$

2.3. Physical Properties of the System

In this study, a parabolic collector with one-axis solar tracking system having properties given below is investigated. The copper is chosen as the material for tube of the collector.

Main thermo-physical and optic properties of the system is listed in Table 1;

Table 1: Thermo-physical and optic properties of collector

Reflector Surface	
Focal length (f)	0.8 m
Collector length (L)	500 m
Diameter of the parabolic aperture area(D)	1 m
Reflection ratio of reflector surface (ρ)	0.9
Collector intersection ratio (γ)	0.95
Collector Pipe	
Material	Selective surface, black nickel plated steel
Outer diameter of tube (d_t)	50 mm
Tube thickness	2 mm
Spesicific heat (c_t)	500 J/kg-K
Heat conduction coefficient (k_t)	54 W/m-K
Absorbtion ratio for solar radiation (α_t)	0.94
Emissivity (ε_t)	0.08
Transparent Cover Tube	
Material	White Glass
Outer diameter of tube (d_g)	10 cm, 15 cm, 20 cm, 25 cm, 30 cm
Tube Thickness	2 mm
Refractive index (n)	1.5
Radiation reduction coefficient (β)	4 m^{-1}
Emissivity of Glass (ε_g)	0.09
Specific heat (c_g)	750 J/kg-K
Heat conduction coefficient (k_g)	1.14 W/m-K
Absorbtion ratio for solar radiation (α_g)	0.08
Thermal Fluid Properties (Dowtherm A) [21]	
Atmospheric boiling temperature	257.1 ºC
Freezing temperature	12.0 ºC
Density (at 25°C)	1056 kg/m^3
Critical temperature	497 ℃
Critical pressure	31.34 bar
Critical volume	3.17 l/kg
Combustion heat	36.053 kJ/kg
Molecular weight	166.0

3. RESULTS AND DISCUSSION

By using the mathematical model given in former section, single and double glass cover collector types are investigated for four different mass flow rates. The fluid temperature values reached at each point of the collector were calculated. Maximum fluid temperature across the collector at the same mass flow rate is given in Table 2.

In Table 3, the collector lengths at where the fluid reaches maximum temperatures for the first time are given.

When Table 2 and Table 3 are examined; It is seen that the temperature reached decreases as the mass flow rate increases. At the lowest mass flow rate of 0.005 kg/s, the highest temperature was reached with the double glass covered system. There was a temperature difference of at least 60 K by comparison with the single glass cover system. It is seen that the double glazing system reaches higher temperatures at shorter distances under the same conditions.

As the mass flow rate increases, the maximum temperatures reached decreases. It is seen that the temperature differences between the single and double glazing systems are reduced. The collector length required to reach the maximum temperature has increased.

The maximum temperature reached at a mass flow rate of 0.1 kg/s, which is the highest flow rate studied, was realized in a single glass covered system. The single glass cover system is more efficient at low temperatures, as flat glass systems [22]

Table 2: Thermo-physical and optic properties of collector

Mass flow rate [kg/s]	For two cover – inner transparent diameter / outer transparent diameter [cm/cm]				For one cover – outer transparent diameter [cm]				
	10/15	10/20	10/25	10/30	10	15	20	25	30
	Temperatures [K]								
0.005	**710,8**	**710,8**	709,8	704,8	651,9	626,6	613,0	604,6	598,8
0.01	**710,8**	710,7	708,4	703,5	651,7	626,5	612,9	604,5	598,7
0.05	**570,3**	567,9	566,3	565,2	561,6	552,4	547,0	543,4	540,8
0.1	463,9	463,3	462,8	462,6	**468.5**	465,7	464,0	462,9	462,0

Table 3: Comparison of single and double cover systems with collector length at where maximum temperature is reached

Mass flow rate [kg/s]	For two cover – Inner transparent diameter/ outer transparent diameter [cm/cm]				For one cover – outer transparent diameter [cm]				
	10/15	10/20	10/25	10/30	10	15	20	25	30
	Collector length at where maximum temperature is reached [m]								
0.005	**155**	**196**	500	500	500	500	500	500	500
0.01	**300**	377	500	500	500	500	500	500	500
0.05	**500**	500	500	500	500	500	500	500	500
0.1	500	500	500	500	**500**	500	500	500	500

4. CONCLUSION

The thermal efficiency is the ratio of the useful energy obtained to the energy consumed. The energy consumed in the examined systems is the solar energy falling on the parabolic reflective beam gap area. The useful energy obtained is the energy transferred to the fluid. In order to increase the efficiency in the examined system, it is necessary to increase the amount of input energy. If it is not possible, the method of increasing the thermal efficiency is to reduce the energy losses.

The main purpose of this study was to reduce losses and increase thermal efficiency with a second glass layer on the receiver pipe. For fluid temperatures between 500 K and 700 K, the double cover system gave successful results. However, for lower fluid temperatures between 0 and 500 K, the double glazing system did not increase efficiency.

As a result; It is seen that for lower fluid temperatures between 0 and 500 K, the double glazing system does not improve performance, but for fluid temperatures between 500 K and 700 K, the double glazing system has higher efficiency. However, a second cover is required in order to exceed the temperatures reached with a single cover.

SYMBOLS AND ABBREVIATIONS

a	Radiation absorption rate, relative width
d_{to},d_t	Outer diameter of collector pipe [m]
D	Relative width, clearance area
f	Focal length [m]
h_f	Heat convection coefficient of fluid [W/m^2-K]
I	Radiation [W/m^2]
k_t	Heat conduction coefficient of collector pipe [W/m-K]
k_g	Heat conduction coefficient of glass tube [W/m- K]
n	Refractive index
q_f	Amount of heat transfer to the fluid [W]
R	Resistance [K/W]
r_{g2i}	Inner radius of second glass tube [m]
r_{g1o}	Outer radius of first glass tube [m]
r_{g2o}	Outer radius of second glass tube [m]
T_f	Temperature of fluid [ºC or ºK]
T_g	Surface temperature of glass tube [ºC or ºK]
T_S	Blackbody temperature of the sun [5762 ºK]
T_{sky}	Temperature of the environment [ºC or ºK]
q_f	Total heat transferred from the pipe [W]

ε_t Emissivity of collector surface

ε_g Emissivity of glass surface

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Apdulmutalip ŞAHİNASLAN1: Performed the experiments and wrote the manuscript.

M. Lütfi BURUNTEKİN: Performed the experiments and wrote the manuscript.

Mesut ÖZTOP : Analysed the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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