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EXERGY OF DIRECT SOLAR RADIATION

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ABSTRACT

The article provides an exergy analysis of the concentration of solar radiation. For the first time, the flux of solar radiation is characterized by its own temperature (radiation), and its exergy is determined within the framework of the canonical Carnot cycle. Based on a new treatment of the temperature of the radiant heat flux, an analytical expression is obtained for the radiation temperature of the solar radiation flux, both for direct solar radiation and for diffuse radiation. The dependence of the density of direct solar radiation on the "mass of the atmosphere" is found. These formulas allow us to calculate the radiation temperature of the solar radiation flux and the exergy flux density on the Earth's surface and in the focus of the concentrator's mirror.

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INTRODUCTION

The exergy method (Gouy & Stodola) of thermodynamic analysis on a par with the entropy method (Gohshtein, 1963), makes it possible to determine the places of the most significant thermodynamic losses in energy conversion processes. Let's recall, for example, that the energy efficiency of a steam generator of traditional TPPs is very close to 100%, whereas its exergic efficiency is only 50%. Thus, the use of such "advanced" scientific tools as exergic analysis allows us to estimate the thermodynamic losses at each stage of the energy conversion scheme and to get an opportunity to reduce them. Therefore, an exergic analysis of the concentration of solar radiation in solar installations with paraboloid mirrors, as well as in optical systems of tower-type solar TPPs with horizontal fields of flat heliostats and TPPs with horizontal parabolic-cylindrical mirrors, clearly demonstrates ways to increase the efficiency of energy conversion in these solar energy systems.

Overview

In a recent article by A.K. Ilyin (Ilyin, 2011), based on a review of the work on the exergy of solar radiation, concluded that the published data in this area are still few and insufficiently defined. Two of the earliest studies of the efficiency ε of the thermal conversion of the radiant energy of the Sun were performed independently by D. Spenner and R. Petela in 1963 (Spanner, 1963; Petela, 1963). Only D. Spenner defined ε as the efficiency of solar energy conversion, and R. Petela defined ε as the ratio of the exergy of solar radiation to the solar constant ($\varepsilon = ex/E_S$). Both of these works were devoted to the problem of "designing" new cycles of converting radiant energy into work. For example, in the R.Petela cycle, solar radiation is a working body that "is compressed by a piston in a cylinder" (Petela, 1965 and Shargut Ya, 1968). On the basis of the analysis of the efficiency of the cycle, he wrote down all the analytical expressions obtained in a general form: in the form of triple integrals, which were not brought to them "before the formula", and even more so, "up to the number." The only concrete formula that was obtained in his work for the efficiency of the new cycle:

$$E = 1 - 4T_o/(3T_S) + (1/3) \cdot (T_o/T_S)^4, \qquad \text{....................(1)}$$

where T_o – ambient temperature, and T_S – emitter temperature.

A similar formula for ε was obtained by D. Spenner:

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$E = 1 - 4T_o/(3T_S)$. ....(2)

An analysis of both formulas shows that they have nothing to do with the expression for the efficiency of the Carnot cycle: $\eta_k = 1 - T_o/T_S$. Thus, here it can immediately be said that R. Petela's work is not devoted to an exergy analysis of solar radiation, but to an evaluation of the effectiveness of a new cycle of conversion of the energy of thermal radiation "constructed" by him. The formula for the efficiency of the new cycle is fundamentally different from the expression for the efficiency of the Carnot cycle with a different coefficient (4/3) for the ratio of temperatures: ambient T_o (waste heat flow) to the temperature T_S of the heat source (in this case the solar disk). Most of the subsequent work on evaluating the e conversion efficiency of solar radiation energy is also devoted to the "design" of new thermodynamic cycles for the conversion of thermal radiation into work (Bell, 1987). One of the latest works with this approach is the article by Kalin Zamfirescu and Ibrahim Dinser, USA (Zamfirescu, 2009). They constructed a completely new photon cycle (the so-called "bottoming" cycle). Solar thermal radiation in this cycle ("bottoming" cycle) is the process of photon emission by the "surface" of the Sun. But the surface of the Sun is a conventional concept - in this case the photosphere radiates (the outer shell of the Sun is about 300 km thick), it has a large temperature gradient in thickness, which falls sharply to the visible "surface" of the solar photosphere. This explains the effect of the "darkening of the edge" of the solar disk, as well as the fact that the brightness of the radiation from the center of the disk (according to Abbot) is 22% higher than the average brightness of the solar disk, and the intensity of radiation in the center is 50% higher than at the edge of the disk. For the same reason, the spectrum of solar radiation differs significantly from the spectrum of thermal radiation of the "absolutely black body" (ABB), determined by Planck's formula. In addition, the question arises why in (Spanner, 1963; Petela, 1963; Shargut, 1968; Bell, 1987; Zamfirescu & I. Dincer 2009), the influence on the temperature T_S is not taken into account the sharp (by more than a quarter) decrease in the density of solar radiation after passage of the atmosphere. A.K. Ilyin (Ilyin, 2011), suggests (in accordance with D. Davins) instead of T_S to use as a thermal radiator an atmosphere layer with a temperature T_a, which is calculated by the formula:

$T_a = \sqrt[4]{E_S/(\alpha_c\sigma)}$, ...(3)

where E_S – flux density of solar radiation on the Earth's surface, W/m^2, α_c – degree of blackness of the system "atmosphere-surface of the Earth", which in (Ilyin, 2011) is determined arbitrarily for different cases, which leads to clearly contradictory results. Thus, the situation in the exergy analysis of solar radiation is very uncertain. First, so far to evaluate the efficiency of the conversion of solar radiation, many "cycles" are used. Secondly, there is no way to determine the temperature of solar radiation. And, thirdly, it is not established how the exergy of solar radiation is affected by losses caused by the absorption of light in the atmosphere, its imperfect reflection from mirrors and the inaccuracy of the optical scheme of the focusing mirror field.

Formulation of the problem

It is known that the maximum efficiency of conversion of heat into energy is given only by the Carnot cycle. Any other thermal cycle gives a lower value of the efficiency of conversion of solar radiation, and accordingly, a smaller value of the exergy of solar radiation. This, by the way, draws attention in an article by Ilyin (2011). Therefore, to estimate the exergy of the solar radiation flux, it is necessary to consider the transformation of its energy only within the framework of the canonical Carnot cycle.

At present, thermodynamics uses the generalized expression (Kirillin, 1983), obtained on the basis of the canonical Carnot cycle, in which the ideal gas is used as the working fluid and which includes two isotherms: with a "greater" temperature of the cycle (temperature of the heat source T_{max}) and with a "smaller" (waste heat temperature T_{min}, i.e. in this case, the ambient temperature), with temperatures T = const, T_0 = const, and the exergy expression is written as:

$$ex_q = q\cdot(1 - \frac{T_0}{T}) = q - T_o\cdot(q/T) \qquad ....(4)$$

In the case where the temperature of the heat supply to the cycle is variable, ($T \neq$ const), for exergy, another expression takes place (Krutov, 1991)

$$ex_q = \int(1 - \frac{T_0}{T})dq = q - T_o\int\frac{dq}{T} \qquad ....(5)$$

An analysis of these relationships shows that to determine the exergy of the radiant heat flux q, it is necessary to determine the expression of the "larger" Carnot cycle temperature (the temperature of the heat source), since the "lower" cycle temperature (ambient temperature) is usually taken for the Earth's surface close to 300 K. Thus, the main task of this study is to clarify the status of the radiant heat flux, as well as the derivation of the analytical expression for the radiation temperature of the radiant flux from the sun (solar radiation), depending on its density and the magnitude of the various optical losses (in its absorption, scattering and reflection) When passing through the atmosphere, reflections from mirrors in the process of focusing in optical systems of paraboloidal solar concentrators, as well as solar thermal power plants (STES) with the concentration of direct solar radiation: STES tower type and STES with parabolic cylindrical mirrors.

RESULTS

New interpretation of the temperature of the photon flux of thermal radiation

In thermodynamics (Kirillin, 1983 and Krutov, 1991), it is assumed that the thermal radiation of the isothermal surface of a closed cavity completely fills it with isotropic radiation, which in the state of thermodynamic equilibrium is the emission of an absolutely black body with a Planck spectrum and which has an intrinsic temperature that coincides with the absolute temperature the surface of this cavity is in accordance with the known Kirchhoff law. In this case, the intrinsic radiation temperature emitted by the hole of the physical model of the ABB designed to calibrate pyrometers, strictly speaking, is not equilibrium, and therefore is called kinetic (Grigoryev, 1974), Such a temperature characterizes all cases in which there is no complete thermodynamic equilibrium (i.e. nonequilibrium processes and systems), although in principle it can be arbitrarily close to equilibrium temperature if certain conditions are met. But in pyrometry, the temperatures of nonequilibrium thermal radiation (brightness T_W and radiation

T_R), measured by the contactless method, unambiguously refer to the radiating surface, although their mathematical expression obviously includes the brightness of the radiation B (spectral or integral). And after all, the brightness T_W and the radiation T_R of the temperature, measured by the pyrometer, may well be attributed to the thermal radiation emitted by the surface itself. And their mathematical expression in this case will relate the temperature of the surface to the intrinsic temperature of the flow of nonequilibrium thermal radiation, which it emits.

It is known that astronomers have long interpreted microwave radiation that fills outer space (the so-called "relict" radiation), like thermal radiation with an absolute temperature of 2.7 K (Charugin, 1975), and generally do not refer it to the radiating surface. In addition, it is known that solar radiation "reaches" to the Earth not instantaneously, but in 8 minutes. That is, the radiant heat flux (photon flux) flies from the Sun to the Earth in space for 8 minutes and all this time it exists by itself completely independently of the emitter. And, finally, in the process of focusing direct solar radiation by a system of mirrors (that is, changing its direction to the opposite direction after reflection from the mirrors into focus) we are already dealing not with radiation directly from the solar disk (which is located in front of the concentrator's mirror), but with reflected radiation coming into focus from the optical (i.e., imaginary) image of the Sun located behind the reflecting mirror. Therefore, it is quite logical here to adopt a new interpretation of the T_{SR} - no longer as the radiation temperature of the solar disk, but as the radiation temperature of the actual solar radiation flux. Since the arguments given above are completely justified, consider further solar radiation as a radiant flux, which can be characterized by a standard parameter - the radiation temperature of the solar radiation flux T_{SR}.

Determination of the temperature of the solar radiation flux at the outer boundary of the earth's atmosphere

If we use a pyrometric approach to determine the brightness temperature of the solar radiation stream, then it will be generally different for different radiation wavelengths, since in general the solar surface (photosphere) emits selectively.

The brightness temperature of the thermal radiation flux along the solar spectrum (Makarova, 1972).

Table 1.

λ, μm	0,305	0,39	0,48	0,56	0,61	0,85	1,45	2,4
T_W, K	5560	5400	5960	5840	5870	5700	6360	5880

Analysis of the data given in the table shows that the brightness temperature over the solar radiation spectrum is highly uneven: it ranges from a minimum of 5400 K (for 0.39 μm) to a maximum of 6360 K (for 1.45 μm), i.e., the difference is about a thousand degrees. Even greater unevenness of the brightness temperature over the spectrum (and no longer continuous, but discrete) will be for solar radiation on the Earth's surface, i.e. after passing through the atmosphere. Thus, in the exergetic analysis of the solar radiation flux, its parameters can be rationally considered within the framework of the radiation (energy) temperature for which the spectral composition of the thermal radiation has practically no value. Therefore, further in this paper, the spectral characteristics of the radiation are not considered.

Radiation temperature of the solar radiation flux

In 2008, in (Ludanov, 2008), a conclusion was drawn on the analytical expression for the radiation temperature of the solar disk. We modify this conclusion in terms of the intrinsic radiation temperature of the solar radiation flux. By the definition given in the standard (GOST 7601-78), the integral brightness of the thermal radiation (in this case of the Sun) is equal to $\bar{B}_s = dE/d\omega$, where E is the density of the thermal radiation of the Sun, W/m^2, ω – solid angle, ster.). The solid angle, in whose solution from the Earth is visible the solar disk $\omega_s = 6{,}8\cdot10^{-5}$ sr. Since the angle ω_s is very small, we can write:

$$B_s = dE_\perp/d\omega \cong E_s/\omega_s. \quad \text{.....................................(7)}$$

On the other hand, the integral brightness of the thermal radiation flux (Makarova, 1972), is equal to $\bar{B} = \sigma T^4/\pi$, где T – radiation temperature. Substituting in this expression the value of the integral brightness of the solar thermal radiation (7), we obtain a simple mathematical expression for the radiation temperature of the solar radiation flux:

$$T_{SR} = \sqrt[4]{[(\pi\cdot \bar{B}_s)/\sigma]} = \sqrt[4]{[(\pi\cdot E_{S0})/(\sigma\cdot\omega_s)]}, \quad \text{.........................(8)}$$

where ω – solid angle, in the solution of which the solar disk is visible (ster.), $\omega = \pi\cdot\sin^2(\varphi/2)$, here φ – flat angle (degrees) at the vertex of the cone spanning the corresponding solid angle ω, sr. For the conditions of the atmospheric space AM0, the standard solar constant is E_{S0} = 1360 W/m^2 [14]. Substituting it into expression (7), we get the value of the brightness of solar radiation over the atmosphere $\bar{B}_s = E_s/\omega_s = 2\cdot10^7$ W/m^{2}ster. And in this case the radiation temperature of the solar-atmospheric beyondatmospheric flux is equal to T_{RS} = 5770 K, which is very close to the accepted value of 5,500 °C in astronomy (5500° + 273° = 5773 K).

Analysis of the parameters of the flux of solar radiation on the Earth's surface

Calculation of the radiation temperature of the solar radiation flux T_R after the passage of the earth's atmosphere by formula (8) shows that it decreases, since a considerable part of it is absorbed by triatomic molecules (mainly gases: ozone and CO_2, and also H_2O vapor). And another, also a significant part, is scattered on the molecules of air gases and aerosol particles, forming a diffuse component of the solar radiation flux. In 1986, the IEC TC No. 82 at the UN adopted a standard for the spectrum of solar radiation at the Earth's surface: the total radiant flux density for AM1.5 is 1000 W/m^2, and the standard direct radiation flux density is 850 W/m^2 for AM1, 5 and not less than 750 W/m^2 for AM3 (Koltun, 1987). It is known that in the flux of solar radiation for AM1.5, the difference between the density of the total flux (1000 W/m^2) and the density of the direct flow (850 W/m^2) represents a stream of so-called diffuse radiation that was formed as a result of scattering by triatomic molecules of air and Atmospheric aerosols. Diffuse radiation propagates within the solid angle enclosed by a cone whose axis coincides with the direction of direct radiation, and the angle at its vertex θ is about 10 deg., (Koltun, 1987 and Zvereva, 1988). On the basis of the formulas obtained above, we estimate the radiation temperatures of the direct and diffuse fluxes of solar radiation for AM1.5, as well as the corresponding exergy fluxes. For a plane angle at the vertex of the cone θ = 10 deg. we obtain $\omega_D = 2.386\cdot10^{-2}$ sr. Substituting the value E_D = 150 W/m^2 and the value of ω_D into formula (8), we get the radiation temperature of the diffuse radiant flux T_S = 768 K (495 ^{o}C).

We estimate the exergy flux density in a diffuse radiant flux of 150 W/m^2 and a temperature of T_D = 768 K. Using formula (4), we find that the exergy flux density is 91.4 W/m^2. As a result, the radiation temperature of the direct-radiation flux of density 850 W/m^2 after passing through the atmosphere AM1.5, calculated by the formula (8), is 5130 K, and the exergy flux density is 800.3 W/m^2, i.e. It is almost an order of magnitude higher than the exergy of the diffuse flux. Accounting for the exergy of the diffuse flux of solar radiation is important in evaluating the exergy efficiency of solar collectors (Ludanov, 2006), since in these solar devices the absorber absorbs not only the direct, but also the diffuse components of the radiant flux. As a result, we obtain that the density of the total exergy flux of solar radiation in this case (AM1.5) is 891.7 W/m^2, i.e. 89% of the total radiation flux (1000 W/m^2).

Dependence of the density of direct solar radiation on its path length in the atmosphere (mass of the atmosphere)

A number of different empirical formulas are known (Koltun, 1987), generalizing data on the optical transmission of solar radiation by the atmosphere:

$\tau_1 = \exp(-c_1 m)$, $\tau_2 = \exp(-s_2\sqrt{m})$, $\tau_3 = 1 - c_3\sqrt{m}$, ... (9)

where m − air mass that is transmitted by direct solar radiation in the atmosphere to the surface: $m = (p/p_o)\cdot\mathrm{cosec}\Theta$, p and p_0 − air pressure at the surface of the earth and at sea level, Θ − angle determining the height of the Sun above the horizon, (deg.).

Calculation of the parameters of the exponent (2) at three points: for AM0 (τ = 1), AM1.5 (τ = 0.664) and AM3 (τ = 0.553) for the case when the empirical constant (**c**) and the exponent of the root of m are unknown, gives the exact values for the empirical constant **c** = 0.4106 and the exponent for m (n = 0.34), the latter is very close to one third (0.333). Rounding the obtained values, we obtain a fairly accurate empirical formula describing the dependence of the direct radiation density of the atmospheric mass of AM (m):

$E_S(m)/E_S(0) = \tau_S(m) = \exp(-0.41\cdot\sqrt[3]{m})$, ...(10)

The resulting formula gives exact values of the direct-flux density for AM0 (1360 W/m^2) and for AM1.5 (850 W/m^2), and for AM3 gives a small error (0.4%). It can be used to calculate the dependence of the transmission τ_S and the exergy of the E_S of the radiant flux on the mass of the atmosphere. The data for calculating the dependence are presented in the table:

Table 2.

AM(m)	0	1	1,5	2	3	5
Θ, deg.	–	90°	41° 49'	30°	19° 27'	11° 32'
τ_S(m), %	100	66,4	62,5	59,7	55,3	49,6
E_S, W/m^2	1360	903	850	812	753	675

As shown above, the change in the exergy of solar radiation is due to a change in the density of the radiant flux and its radiation temperature. If we take into account that after the passage of the atmosphere the density of the direct solar radiation has decreased (because of absorption and scattering), then its radiation temperature decreases in accordance with formula (8), and since $E_{SM} = E_{S0}\cdot(\tau_S)_m$, then it will be:

$T_{SR} = \sqrt[4]{[(\pi\cdot E_{S0}\cdot\tau_S)/(\sigma\cdot\omega_s)]} = (T_{SR})_o\cdot\sqrt[4]{(\tau_S)_m}$ ....(11)

According to formula (11), the dependence of the radiation temperature T_{SR} on the mass of the atmosphere can be calculated. And if we assume that T_o = 300 K, then we can determine the dependence of the exergy of the SI flux on the mass of the atmosphere. The calculation data is summarized in the table:

Table 3.

AM(m)	0	1	1,5	2	3	5
E_S, W/m^2	1360	903	850	812	753	675
T_{SR}, K	5770	5350	5130	5070	4974	4840
ex_q, W/m^2	–	852,3	800,3	764,0	707,6	633,2

Loss of exergy (anergy), which occur when the radiant flux is focused in the elements of the optical scheme of solar thermal power plants (STES)

On the basis of the results obtained above, we analyze the change in the density of the radiant flux and its radiation temperature in the mirror concentrating systems of STPP (Strebkov, 2007). After reflecting the flux of solar radiation from the mirrors of concentrators, its radiation temperature decreases due to the fact that the reflection coefficient of the metal layer of mirrors is less than one (for aluminium R_{Al} = 0.9), and in addition, due to the increase in the solid angle of the image of the Sun, which is caused by imperfection of mirrors (the inaccuracy of the optical circuit and the roughness of the reflecting surface):

$T_{SR} = \sqrt[4]{[R_{Al}(\pi\cdot E_{S0})/(\sigma\cdot\omega^*)]}$, ...(12)

where ω^* − solid angle of the solar disk image enlarged by errors, $\omega^* = \pi\cdot\sin^2(\varphi^*/2)$, $\varphi^* = \varphi + 2\delta$. At best, for paraboloid mirrors with a polished reflective layer of mirrors, the error angle δ due to the roughness is about 20% of the angular dimension of the sun φ. But usually for real STPP the error δ is much greater due to inaccuracy of the focusing scheme. If for R_{Al} = 0.9 the temperature of the radiation flux decreases only by 2.6% in reflection, then if the angular error δ is 50% of the angle φ, then the radiant temperature T_{SR} of the radiant flux after the optical mirror circuit is reduced by almost a third (by 29.3%). And with a decrease in the radiation temperature of the solar radiation flux, for example, for AM1.5 (850 W/m^2) from 5130 K to 3530 K, after reflecting the radiation from the mirrors of the concentrator (or heliostat field) towards the focus, the exergy content in the radiant flux decreases (by 8.5%). Thus, inaccuracies in the optical scheme of the STPP when focusing the radiant flux by mirrors lead to large thermodynamic losses, i.e., to losses of exergy (to the generation of energy). In addition, when the bundle of concentrated solar radiation falls on the surface of the STPP helium receiver, significant losses of exergy also appear. If the beam falls on the helio-receiving surface at an angle of ψ, then the density of the radiant flux is reduced: $E_S = E_{S0}\cdot\cos\psi$, which in turn decreases the radiation temperature of the solar radiation T_{SR}, and accordingly, the amount of the exergy flux incident on the solar collector. Analysis of the concentrated radiant flux shows that in the process of focusing solar radiation on the STPP solar collector, its density increases in proportion to the degree of concentration N ~ Ω/ω, which is equal to the ratio of the two solid angles corresponding to the optical (i.e., imaginary) image of the Sun (Ω = Σω*) And its real image ω, more precisely: $N = (\Sigma\omega^* \cdot \cos\psi_i)/\omega$. The optical image of the Sun is formed by a beam of rays reflected by heliostats. It can be seen from the focus in the solution of the solid angle Ω. But the ratio of the exergy flux to the energy flux is thereby reduced - due to optical losses caused by the imperfect focusing of the STPP mirrors and the non-perpendicularity of the beam falling onto the solar receiver surface, since the radiation temperature of the solar radiation flux decreases, and so does the corresponding exergy flux.

Evaluation of exergic losses (anergy) on STPP of various types

It is known (Strebkov, 2007), that the degree of concentration of solar radiation in STPP with horizontal parabolic-cylindrical mirrors is small: N = 60-80, and the temperature of the coolant that removes heat from the linear solar receiver hardly reaches 400 ^{o}C. The degree of concentration of solar radiation in large STPP tower type with flat mirrors-heliostats is N = 800-1200, while the surface temperature of the solar receiver at noon reaches 700^{o}C, and the coolant in the channels of the solar collector on the STPP tower is even smaller - 540^{o}C. The greatest degree of concentration is achieved in the STPP module with a paraboloidal mirror - N is about 2.5 thousand in it, and the temperature at the surface of the Stirling engine's solar receiver, set at its focus, exceeds 1000 °C. Comparison of the radiation temperature levels of the solar radiation flux incident on the surface of the STES mirrors (about 5 thousand K) and the temperature level in the STPP solar collectors (maximum 1000 °C) shows that it is on the surface of the STPP solar power receivers that (by more than five times) The temperature of the radiant flux, and accordingly, because of these losses, the exergy flux density decreases several times. Thus, it is during the absorption of concentrated solar radiation by the working surface of the STPP helioreceiver (through which the working medium of its power plant is pumped through) that the main thermodynamic losses of energy conversion occur at modern STPP. However, the maximum temperature of the coolant in the solar collectors of large STPP is limited not by the degree of concentration, but by the capabilities of modern types of turbines (steam turbine units) whose temperature limit is limited by the strength of the steam turbine blades (maximum ~ 650 °C). Therefore, in order to increase the efficiency of large STPP, it is necessary to shift to the use of power plants with a higher "upper" temperature of the cycle. This can be done by using a thermoemission "superstructure" in a binary cycle (Kokorev, 1980) with a PTU (T_{max} = 1500 ^{o}C) or on the basis of a new method of direct energy conversion within the framework of the electrochemical mechanism (Patent, 2008), which already today allows conversion of heat in an energy installation STPP at the value of the "upper" cycle temperature T_{max} = 1200^{o}C.

Conclusions

It has been shown for the first time that the exergy of solar radiation should not be determined on the basis of the "design" of new photon cycles, it must be interpreted as the result of the conversion of the radiant heat flux within the framework of the canonical Carnot cycle, for which the main role is played by the density of incident solar radiation and the radiation temperature of the radiant thermal Flux (photon flux). In the article, for the first time, the flux of solar radiation is characterized by its own radiation temperature, which no longer directly relates to the thermal radiator, i.e. To the radiating "surface" of the solar disk. An analytical expression for the radiation temperature of the direct and diffuse components of the solar radiation flux is obtained and an exact empirical expression for the exponential dependence of the density of direct solar radiation on its path length in the atmosphere (on the "mass of the atmosphere" AM) is obtained.

It is shown that the radiation temperature of the direct solar radiation flux decreases with decreasing radiant flux density during its absorption and scattering in the earth's atmosphere (mainly by triatomic molecules: CO_2 gas and H_2O vapor, as well as aerosols). It is established that the ratio of the exergy flux to the energy of the radiant flux in the process of its concentration in the optical systems of the STPP does not depend on the degree of concentration, but is determined only by optical losses during focusing. The increase in the efficiency of STPP due to the concentration of solar radiation is provided solely due to a considerable (by several orders of magnitude) decrease in heat loss from the heated surface of the solar receivers, while the radiation temperature of the solar radiation flux decreases with the system of focusing mirrors. It is shown that the main source of thermodynamic losses in STPP takes place in its solar collector, where the flux of direct solar radiation with a radiation temperature of about 5 thousand K is absorbed by the surface of the absorber and transferred to the heat carrier with a temperature of ~ 5 times lower.

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