ISSN 2278-3091

Volume 9, No.4, July – August 2020

International Journal of Advanced Trends in Computer Science and Engineering

Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse208942020.pdf

https://doi.org/10.30534/ijatcse/2020/208942020

Computation of Heat Transfer on Flat Solar Collector Upper Surface and Power Balance of Solar Heat Supply System

Didar Yedilkhan [1], Murat Kunelbayev[2*], Ainur Kozbakova[3], Omirlan Auelbekov[4], Nazbek Katayev[5], Miras Amirgaliyev [6]

[1,2*,3,4,5,6]Institute Information and Computational Technologies CS MES RK, Almaty Kazakhstan,

[1]yedilkhan@gmail.com, [2*]murat7508@yandex.kz, [3]ainur79@mail.ru, [4]omirlan@mail.ru, [5]k_nazbek@mail.ru, [6]miras_amirgaliyev@mail.ru

ABSTRACT

In the work herein there is considered the heat transfer computation at the solar collector and environment boundaries and solar heat supply system energy balance. Heat exchange and heat transfer occur simultaneously by several means: conduction, convection and irradiation. Role of heat transfer in solar collector total heat transfer means is different and depends both on its material elements' thermal-physical characteristics and air medium, circumfluous solar collector's external and internal surfaces We have computed the solar power value from the horizontal surface for summer and autumn seasons in the Republic of Kazakhstan.

Key words: flat solar collector, heat transfer, energy balance, solar heat supply system

1. INTRODUCTION

Fossil fuel ad nuclear power for sustainable energy resources development at present time shall be, on the operational basis, replaced with renewable energy sources. Renewable energy sources are stable and able to satisfy current and future predicted global needs in power without any affect at the environment. For sustainable meeting the global energetics demands, renewable energy sources such as, solar energy, wind, hydropower and biogas are the appropriate alternatives. The best choice for satisfying the ever growing demand for energy is solar power. Transformation of solar irradiation into heat is one of the simplest and direct means of using its power. Flat solar collector is an installation, used for transforming the solar energy into thermal one. Flat solar collectors most frequently used all over the world in commercial and domestic systems of water heating. Therefore, domestic sector might decrease influence at the environment, installing flat solar collectors for water heating. Flat plates, evacuated tubes or concentration collectors are solar collectors for domestic use hot water. The most often used type for low temperature media is a single-layered flat plate.

Solar water heating principal element is a flat plate collector. Absorber plate serves as the collector's central element. Solar collector thermal characteristics depend on optic and thermal features and thermal properties, as well on absorber's plate design. Standard flat collector consists of absorber in the insulated box together with translucent coating (glazing). Absorber is usually made of metal sheet with high heat conductivity, such as copper or aluminum with build-in or connected tubes. Its surface is covered with special selective material to maximize radiant energy absorption at minimizations of radiant energy irradiation, Insulated box lowers heat losses on flat collector from its back and sideways [1]. The simplest and most widely used collector is a thermosiphon or natural circulation system of solar water heating systems (SWHS). It consists of plate collector, accumulating reservoir, and connecting tubes. Collector consists of absorber plate, riser and manifold pipes, glass cover, body and insulation. Due to difference in density the water in tubes heats and directs to a storage tank. The flow depends on thermosiphon head, which, in its turn, depends on buoyancy effect, which is linked with water density change, due to temperature increase in the solar collector. In the works [2,3] there has been conducted a number of experiments on transforming the solar energy into heat. There have been fulfilled various works, using a single phase technology of heat transfer. In the researches [4-7] the experiments have been conducted in the solar collector with flat plates, using a single-phase hear-exchange process, using uninsulated water reservoir and uninsulated connecting tube, as well insulated water tank and insulated pipe. For that aim, a flat solar collector functions as a heater, and water tank maintains hot water. There is a possibility to cut huge heat losses from the reservoir and connecting tube. Final result is increase of water temperature and flat collector productivity upgrading. Flat solar collector is usually used for transforming the solar energy into thermal energy. Collector in heating and water supply systems is designed for moderate temperature. Thanks to expenditures absence om electric power, comparing to conventional electrical heating, usage of solar water heaters plays an important role [8]. Solar collector productivity lowers due to higher thermal loss factor at upper surface, and, accordingly, due to capacity loss due to low thermal characteristics [9]. It has been defined, that total heat losses up to 75% occur from the collectors' upper part side [10]. The work describes a newly developed calculation technique and the choice of the geometrical parameters of the solar collector with the siphon effect [11]. The paper herein considers the study of convective heat transfer in flat plate solar collectors, as it is seen from the analysis on research of the heat transfer by a circular and flat tubes upon conforming the forced and free convections, placed vertically or horizontally with various liquid flow directions. There have been obtained Nusselt criterion dependencies in circular and flat pipes, which show, that corresponding equations allow defining the heat transfer intensity for all fluids with appropriate accuracy [12]. The article herein considers the mathematical models of separate constructions and functioning modes of the double-circuit solar collector with thermosyphon circulation. To execute the task thereof, we have considered developed by us a new construction flat solar collector with thermosyphon circulation, in which the heat transmission factor has been increased at the expense of removing the additional partitions between a panel and heat insulation. The considered solar collector performance is achieved due to availability of a tank dozer and thermal pump in the design, where a condenser and evaporator have been executed in the form of a heat exchanger of «spiral in spiral» type, and heat exchangers pipelines are placed one above another, allowing to increase the square and heat exchange intensity. An outcome of this work is theoretical and mathematical analysis of non-stationary thermal regime of flat plate solar collectors in the functioning modes being considered. Based on the analysis results we can optimize the designs individual elements, as well forecast the thermal mode and select the alternative solutions on the flat solar collectors' design and operation regimes [13].

2. RESEARCH METHODOLOGY

The solar heat supply system with a controller has been constructed at the Institute of information and computer technologies in Almaty city, Republic of Kazakhstan.

The device has been elaborated without a wire, cheaper, than accessible solution and simpler in implementation, in order to avoid the problem of the device connection inside the building far from a solar panel. The system assumes the installation of an external heat exchanger, designed for simulating hot water consumption or heat diffusion at the temperature inside a boiler exceeding the fixed value, prescribed as the maximum threshold. Control unit consists of external wireless and solar autonomous power supply unit, which transmits data on the solar panel temperature (T1) to internal control module, which obtains data and manages the system, controlling the temperature values and two electrical pumps conditions. Figure 1 shows the scheme of solar heat supply system with a controller.

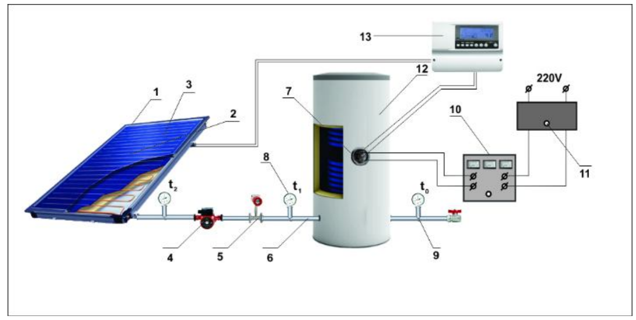

Figure 1: Principal system of solar heat supply with a controller

1 – heat-insulated body; 2 – translucent cover; 3 – tank-absorber; 4-circulating pump; 5 – flowmeter; 6 – pipeline; 7 – THE; 8, 9 – thermometers for water temperature measuring at inlet and outlet from the tank-absorber and environment; 10 - set of electric measuring tools К 501; 11 – autotransformer; 12- tank-accumulator; 13-controller. Laboratory stand scheme consists of heat-insulated body 1, translucent cover 2, tank-absorber 3, circulating pump 4, flowmeter 5, pipelines 6, thermal electric heater with heat regulator 7, thermometers 8, 9, for measuring water temperature at inlet (t1) an at outlet (t2) from the tank and environment (tm), measuring device К 501 and autotransformer 11, as well, a controller for the management system.

For rational heat removing from heat transmitting solar collectors and simplifying the solar system operation it is obviously advantageous, that the system thereof operates with thermosyphon circulation. Therefore, to determine the solar plant thermal regimes it is necessary to define the efficiency dependence on regime characteristics of density, solar radiation, heat removal factor, outside temperature, temperatures difference, etc.

Figure 2 presents the flat plate solar collector mockup. Content and novelty are in the fact, that in distinction from the known designing principle, the collector contains a transparent glazing unit 2 with double glass and decreased pressure, as well, a perimetric frame 1. Wooden frame bottom 7 is made of 8mm thickness plywood with an attached heat insulation film 5 of foil. In the gap between a glazing unit and bottom there is laid a flexible thin-walled stainless corrugated tube 4 16 mm in the coil form. Pipe edges are fixed to inlet and outlet protruding tubes 6

Figure 2: Principal Diagram of a Flat Solar Collector

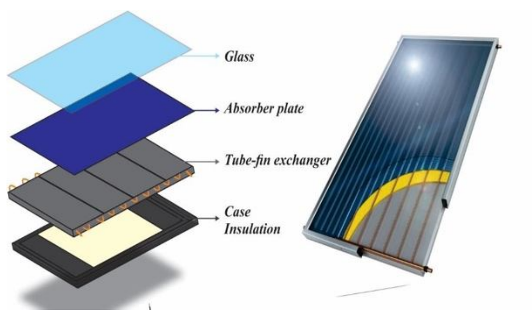

Figure 3: Principal Diagram of Knocked Down Flat Plate Solar Collector

As it is shown on the Figure 3, the solar energy goes through the glass and bumps onto the absorber's plate, which is heated, transforming the solar energy into the thermal one. The heat is transferred to the working fluid, which passes through the tubes, attached to the absorber's plate.

Figure 4: Flat plate collector mockup

Figure 4 shows flat plate collector's mockup. The solar collector is the main heat generating unit of the solar plant. To reach the set aim, we have developed a principally new flat solar collector, based on which there will be constructed the standard series solar plants for hot water supply and premises and buildings heating.

Table 1: Technical Specifications of Flat Plate Solar Collector

Parameters	Value
Absorbing plate material	copper
Absorber plate dimensions	2 m×1 m
Plate thickness	0.4 mm
Glazing material	Hardened glass
Glazing dimensions	2 m×1 m
Glazing thickness	4 mm
Insulation Collector's tilt angle	Foam plex (foam $45^{\cup}$
Absorber's thermal	401 W/(m K)
Insulation thermal	0.04 W/(m K)
Transmittance-absorption	0.855

2.1 Heat Transfer computation on Solar Collector Upper Surface

To formulate the conditions at the boundary "the upper surface of the solar collector - the adjacent layer of air" we introduce the following simplifications:

- The boundary surface "surface of the solar collector - adjacent layer of air" is the surface of the solar collector in contact with the outside air;
- the thermophysical characteristics of the external elements of the solar collector and the adjacent layer of air, as well as the meteorological parameters along the surface of the solar collector, do not change.

In view of the foregoing, and taking into account the scheme of heat flows through the upper surface "collector - adjacent layer of air", the heat balance equation on that surface will take the form:

Heat and mass transfer in the copper tubular spiral of the collector is more convenient to consider as below

$$q_{\sum heat\ flux} = q_{heat\ flows} - q_{convection} - q_{thermal\ radiation} \quad (1)$$

where $q_{\sum heat\ flux}$- density of heat flux, flowing through the solar collector's upper surface, Wt./m^2; $q_{heat\ flows}, q_{convection}, q_{thermal\ radition}$ – density of heat flows, conditioned with the intensity of solar irradiation, convection and thermal radiation from the solar collector surface, accordingly, Wt./m^2

$$q_p = q_p^{ref} + q_d \quad (2)$$

Geometrical ratios, describing the position of a plane, oriented in a certain way relative to the Earth at any moment in time and direct solar radiation, that is, the position of the Sun in reference to this plane, can be written, using a number of angles. For a plane, oriented at an arbitrary way, that expression will have the form [7]:

$$\cos(\theta) = \sin(\delta) \cdot \sin(\varphi) \cdot \cos(S) - \sin(\delta) \quad .$$

$$\cos(\varphi)\cdot\sin(S)\cdot\cos(\gamma)+\cos(\delta)\cdot\cos(\varphi)\cdot\cos(S)\cdot\cos(\omega)+\cos(\delta)\cdot\sin(\varphi)\cdot\cos(\gamma)\cdot\cos(\omega)+\cos(\delta)\cdot\sin(S)\cdot\sin(\gamma)\cdot\sin(\omega) \quad (3)$$

where θ - direct solar radiation incidence angle, measured between radiation direction and normal to surface, δ – solar decline, that is, Sun angular position in midday in respect to equator plane (positive for northern hemisphere), φ – latitude area (positive for northern hemisphere), S – angle between the plane being considered and horizontal sirface (that is iclination), γ – plane azimuth angle, that is, normal perturbation to the plane from local meridian (point of reference is southerly direction, direction to the East is considered to be positive, to the West – negative), ω – clocking angle, equal to zero in sunny midday, each hour corresponds to 15˚ of longitude, at that, hour angle values till the midday are considered to be positive, and after midday-negative, for instance, ω =15˚ at13.00 and ω =37,5˚ at 15.30).

An hour angle in sunny day is computed

$$\omega = 180 - \left(\frac{180}{12}\right)\tau \quad (4)$$

Deflection might be defined according to a formula as in [9]

$$\delta = 23.45\cdot\sin\left[360\cdot\frac{284+n}{365}\right] \quad (5)$$

where n – order number of the day.

Thus, solar radiation intensity on collector' upper surface is computed according to a formula

$$q_p = \left(q_{surf}\cdot\cos(\theta(\tau)) + q_d\right) \quad (6)$$

As you know, part of the radiation incident on any surface is reflected from it. A value, characterizing the reflectivity of a surface is estimated using a thermal physical characteristic, called albedo and is determined by the thermal and physical characteristic, called albedo and is defined with the ratio

$$r_{al} = \frac{q_p^{ref}}{q_p} \quad (7)$$

A large role in the heat transfer on the upper surface of the collector plays convection.

The law of convective heat transfer is quite complicated, but for practical calculations it can be accepted in the form of Newton's law [10, 11]

$$q_{convectiv\ heat\ transfer} = \alpha_{factor}\left(t_{upper\ surface} - t_{surface\ air}\right) \quad (8)$$

where α_{factor} – convective heat transfer factor, Wt./m2·K; $t_{surface\ air}$ – temperature of surface air; $t_{upper\ surface}$ - temperature of collector's upper surface.

Numerical value of heat exchange convective factor might be computed both according to experimental data and to simplified formulae.

Upon engineering calculations, high accuracy is not required, and information, that can be used as the source data is very limited. Based on the foregoing, simplified definition formulae are of some practical interest.

Let's consider, for example, the formulae in [10].

Heat transfer convective factor is computed according to Urgens formula

$$\alpha_{heat\ transfer\ convective\ factor} = 6{,}17 + 4{,}19v_i \quad (9)$$

As well, is computed according to Riman formula

$$\alpha_{heat\ transfer\ factor} = 6{,}17 + 3{,}61v_i \quad (10)$$

where *v*в – near the ground air speed, m.

The expressions thereof reasonably to replace with one equation, averaging the coefficients at wind speed:

$$\alpha_{heat\ transfer\ facror} = 6{,}17 + 3{,}9v_i \quad (11)$$

Thus, value computation is simple and demands as initial data only the information about the air motion rate.

Rate of heat flow, caused with radiant interchange between collector upper surface and adjoining air layer might be computed according to the formula [10, 11]

$$q_{rate\ of\ heat\ flow} = \sigma_0\cdot\varepsilon_{emm.fac}\cdot\left(\left(\frac{T_{upp.sur}}{100}\right)^4 - \left(\frac{T_{adj}}{100}\right)^4\right) \quad (12)$$

Where σ_0 - Stefan-Boltzmann universal constant, σ_0 =5,7, Wt./(m2K4); $\varepsilon_{emm.factory}$ - emissivity factor of collector element's upper surface, made of translucent material (see Fig. 2); $T_{upp.sur}$ – temperature of collector's upper surface, K; T_{adj} - temperature of adjoining air layer, K.

For the element surface, made, for instance, of cellular polycarbonate $\varepsilon_{emm.fac} = 0{,}15$ [12].

The difference of the fourth degrees in the formulae in practical calculations is inconvenient. And it is customary to carry out engineering calculations, using not the absolute temperature scale, but the Celsius scale. Therefore, we introduce a coefficient linearizing formula (11), the so-called temperature multiplier factor k_t [13].

$$k_t = \frac{\left(\left(\frac{T_{upp.sur}}{100}\right)^4 - \left(\frac{T_{adj}}{100}\right)^4\right)}{T_{sn} - T_s} \quad (13)$$

Temperature multiplier factor values on practically significant for computation temperature range are given in Table 2.

Table 2: Values of Temperature Coefficients

Temperature range, ^oC	Temperature coefficient
0 - 20	0,9
20 - 40	1,1
40 - 60	1,35
60 - 80	1,65

In the denoted Table 2 the temperature range at maximum error for temperature multiplier k_t does not exceed 3%. Table 2 data gives convenient expression k_t computation

$$k_t = 0{,}819 + 0{,}0075 \cdot t + 0{,}0000625 \cdot t^2 \quad (14)$$

By using the k_t coefficient, the equation for calculating the radiant component of the heat flux from the surface of the solar collector can be written in the same form as for the convective component

$$q_{rad.comp} = \alpha_{rad.comp}\left(t_{upper\ surface} - t_{surface\ air}\right) \quad (15)$$

This is convenient for the experimental determination of the heat transfer coefficient from the surface, when the heat exchange, caused by convection and radiation cannot be separated [10, 13].

After substituting expressions (9, 11) and (15) for heat fluxes in the heat balance equation (4) taking into account the albedo, we have obtained the boundary conditions on the upper surface of the collector in the form

$$\lambda_1\left(\frac{dt_1}{dy}\right)_\pi = \left(q_{rate\ of\ heat\ flow} \cdot \cos(\theta(\tau)) + q_d\right) \cdot r_{al} - \alpha_{heat\ tranfer\ factor}\left(t_{upper\ surface} - t_{surface\ air}\right) - \alpha_{heat\ tranfer\ convective\ factor}\left(t_{upper\ surface} - t_{surface\ air}\right)$$

(16)

2.2 Energy Balance computation for Solar Heat Supply System

To calculate the energy balance of the solar system, it is necessary, that the facts, characterizing the intense directions and method of solar radiation fall onto the transparent surface of the solar collector. Solar radiation intensively affects the surface of the solar collector in a wide range, depending on the height of the solar and angular incidence of sunlight, a transparent atmosphere and air humidity.

Periodic weakening of the height of the solar and angular incidence of sunlight, can be considered using the formula

$$\frac{10-n}{10}E_1\varepsilon_1 d\tau + \frac{10-n}{10}E_2\varepsilon_2 d\tau + E_3\varepsilon_3 d\tau + \frac{10-n}{10}E_4\varepsilon_4 d\tau = E_0(\varphi, \sigma, \eta, \varepsilon, U, T_0) \quad (17)$$

where n-clouds, ε_1- - falling surface absorption factor, φ- air humidity, η-index of reflection from the ground surface, E_1 - straight-line solar irradiation, E_2 – earth surface partial beam, E_4– solar irradiation in cloudy day, E_5- solar beams at flat earth surface.

Solar beams can be computed according to the formula

$$E_3 = C_r T_0^4 \quad (18)$$

when T_0- ambient air temperature. Irradiation intensity average is computed as:

$$E_4 = \sqrt{sin\beta} \quad (19)$$

Based on experimental data the irradiation intensity average value is calculated

$$E_4 = 90n^{1/3} sin\beta \quad (20)$$

According to Burger formula the solar irradiation direct intensity, when P-atmosphere index of the Republic of Kazakhstan shall be 0,75

$$E_1 = Q_0 P^m \quad (21)$$

Atmosphere mass should be computed according to the known formulae:

$$m = \frac{H}{H_0}\frac{J}{58{,}36'' cos\beta} \quad (22)$$

$$J = 21{,}25\frac{H}{H_0}tg\left(\frac{\pi}{2} - \beta\right) \quad (23)$$

at j-refraction, H-pressure and temperature. If place into the earth the level H = 760 mm of mercury Q= 1,9 kkal/cm^{2}min

If solar irradiation surface is perpendicular to the solar beams, we define

$$E_1 - 0.75\frac{280}{T_0 sin\beta(Kcosi + E} \quad (24)$$

Let's consider transparent beam coefficient.

Values of sun rays for latitude and eastern surface should be found in the formula:

$$sin\beta = cos\delta cos\varphi + sin\varphi sun\delta \quad (25)$$

when φ - geographic latitude, degrees; δ- solar declination, degrees; γ – time angle, degrees.

Table 3: Values of Summer and Autumn Solstices in the Republic of Kazakhstan

Solar highly		1	3	5	10	20	30	60	90
Summer	Eyne	54,5	148	226	372	550	654	786	815
	Ehor	0,95	7,7	419,7	64,5	188	326	681	815
Autumn	Eins	57,3	158	243	398	588	699	840	870
	Ehor	1,00	8,2	521,2	69,0	201	349	726	870

3. RESULT

Results of experimental works are computations of heat transfer on the solar collector's upper surface and energy balance of solar heat supply system

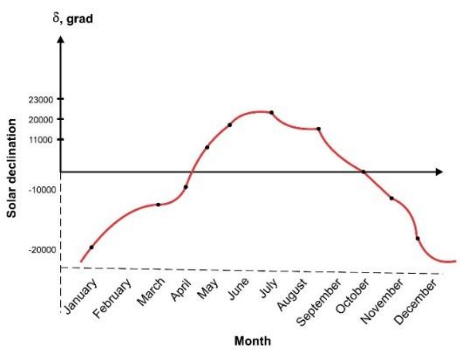

Figure. 5:. Solar declination amount for each month's 21 date on the territory of the Republic of Kazakhstan

Figure 5 shows the number of solar declines on the 21st day of every month in the Republic of Kazakhstan. As you can see, in summer, the solar declination is very high due to high solar radiation, and in winter, the solar declination is very low, since solar radiation is low.

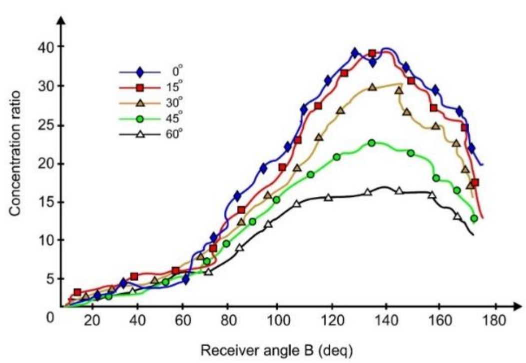

Figure 6: Values of summer and autumn solstice in the Republic of Kazakhstan

As we see from Figure 6, the summer and autumn solstices for the Republic of Kazakhstan, depend on the concentration coefficient of solar radiation. The higher the concentration coefficient, the higher the average value of the radiation intensity. With a larger angle of incidence of sunlight, the lower the concentration of solar radiation. It follows from the Burger formula, that at average angles of incidence of sunlight, the radiation concentration will be higher.

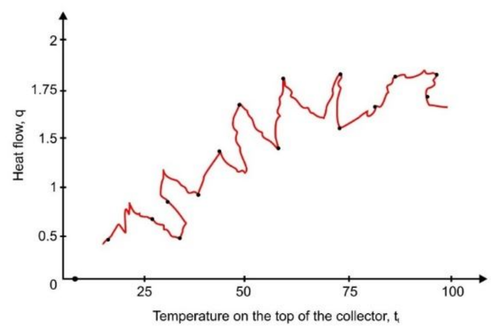

Figure 7: Dependence of heat flux from solar collector upper part

Figure 7 shows the dependence of the heat flux on the temperature of the solar collector's upper part. As can be seen from the figure, when sunlight enters the upper part of the solar collector, the heat flux increases, as a result of the solar radiation high intensity.

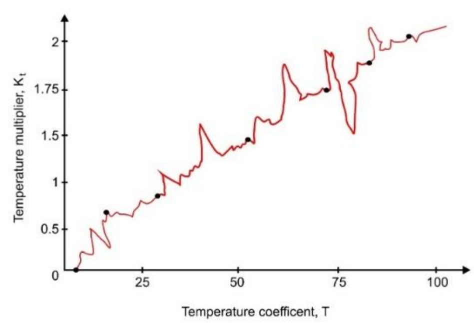

Figure.8: Values of temperature multipliers on practically significant temperature range for computation

Figure 8 shows the values of the temperature factors in a temperature range, that is practically significant for the calculation. As can be seen from the figure, the temperature factor depends on the heat flux from the solar collector's surface, as well as convective heat transfer between solar radiation and the surface of the solar collector.

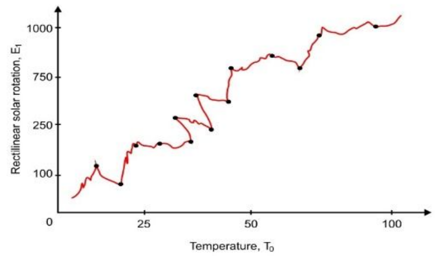

Figure 9: Dependence of rectilinear irradiation on solar collector temperature

As you can see from the graph, rectilinear solar radiation falling on the upper surface of the solar collector increases along with convective heat transfer and the intensity of thermal radiation of solar energy. In this case, the temperature of the solar collector, according to the first law of thermodynamics and the thermophysical properties of the solar collector increases due to radiant heat exchange.

4.CONCLUSION

In this work, the boundary conditions of heat transfer on the upper surface of the solar collector are calculated. The boundary surface “the solar collector surface - the adjacent layer of air” was determined, which is the surface, coinciding with the surface of the solar collector in contact with the outside air; the thermophysical characteristics of the external elements of the solar collector and the adjacent air layer, as well as the meteorological parameters along the surface of the solar collector are not changed. The heat flux due to solar radiation, as well as the heat flux due to radiant heat exchange are computed. The energy balance of the solar heat supply system is also calculated, which shows, that at high altitude, intense solar rays depend quite strongly on solar radiation, and at sufficiently high solar radiation, a small change in solar radiation is very large to reduce the solar radiation.

ACKNOWLEDGEMENT

This work was supported by a grant from the MES RK BR05236693, carried out at the Institute of Information and Computational Technologies of the CN of the MES RK, under Contract No. 318 dated 03.30.2018

REFERENCES

[1] Duffie, J. A, and W. A. Beckman. **Solar Engineering of Thermal Processes**, John Wiley and Sons, New York, 1991,ch.4.

[2] Ahmet Samanci and Adnan Berber. **Experimental investigation of single-phase and two phase closed thermosyphon solar water heater systems**, Scientific Research and Essays, Vol. 6(4), pp. 688-693, February, 2011.

[3] M. A. Islam, M. A. R. Khan and M. A. R. Sarkar. **Performance of a Two-Phase Solar Collector in Water Heating**, Journal of Energy & Environment, Technical Note, pp. 117 – 123, Jan. 2005.

[4] K. Chuawittayawuth and S. Kumar.**Experimental investigation of temperature and flow distribution in a thermosyphon solar water heating system**, Renewable Energy 26, pp.431–448, July 2002.

[5] H. Taherian, A. Rezania, S. Sadeghi and D.D. Ganji. **Experimental validation of dynamic simulation of the flat plate collector in a closed thermosyphon solar water heater**, Energy Conversion and Management 52, pp.301–307, January 2011.
https://doi.org/10.1016/j.enconman.2010.06.063

[6] Samuel Luna Abreu, Sergio Colle. **An experimental study of two-phase closed thermosyphons for compact solar domestic hot-water system**, Solar Energy 76, pp. 141–145, March 2004.

[7] Alireza Hobbi, Kamran Siddiqui. **Experimental study on the effect of heat transfer enhancement devices in flat-plate solar collectors**, International Journal of Heat and Mass Transfer 52, pp.4650–4658, May 2009.

[8] N. V. Ogueke, E. E. Anyanwu and O. V. Ekechukwu. **A review of solar water heating systems**, Journal of Renewable and Sustainable Energy 1, 043106, July 2009.

[9] Dr. Akeel Abdullah Mohammed. **Heat Transfer and Pressure Drop Characteristics of Turbulent Flow in a Tube Fitted With Conical Ring and Twisted Tape Inserts** Engg. & Tech. Journal, vol. 29, no. 2, August 2011.

[10] Nuntaphan, Atipoang, Choosak Cansena, and Tanongkiat Kiatsiriroat. **Performance analysis of solar water heater combined with heat pump using refrigerant mixture**. *Applied Energy* 86, no. 5, pp.748-756, May 2009

[11] Ye. N. Amirgaliyev, M. Kunelbayev, A.U. Kalizhanova, O. A, Auelbekov, N. S. Kataev, A. Kh. Kozbakova. **Study of convective heat transfer in flat plate solar collectors**. Journal WSEAS Transactions on Systems and Control, vol. 14, pp.129-137, April 2019.

[12] Ye. N. Amirgaliyev, M. Kunelbayev, A.U. Kalizhanova, W. Wójcik, B. Amirgaliyev, O. A, Auelbekov, N. S. Kataev, A. Kh. Kozbakova. **Calculation and selection of flat-plate solar collector geometric parameters with thermosiphon circulation,** Journal of Ecological Engineering, Vol. 19, 6, pp.176-181,November 2018.
https://doi.org/10.12911/22998993/91882

[13] Yedilkhan Amirgaliyev, Murat Kunelbayev, Aliya Kalizhanova, Omirlan Auelbekov, Nazbek Katayev, Ainur Kozbakova. **Theoretical and Mathematical Analysis of Double - circuit Solar Station with ThermoSiphon Circulation**, Journal of Polytechni,.22 (21), pp.485-493, February 2019.