Results of the calculation of the absorber temperature in a flat solar air heater

Yorqin Abbasov[1*], *Muyassar* Umurzakova[1], and *Salokhiddin* Sharofov[1]

[1]Fergana Polytechnic Institute, Uzbekistan

Abstract. The article discusses a method for calculating the temperature of the solar air heater absorber under conditions of still air in the collector and under conditions of low forced convection. The problem of determining the temperature of the air heater absorber tst is considered for the climatic conditions of Fergana, with a horizontal collector and when solar radiation passes through double glass. It is assumed that over the considered short period of time, the temperature of the absorber is constant and the heat loss through the insulation of the bottom of the collector is negligible. Solar radiation passes through ordinary transparent colorless glass with a reflectance of 8%. Taking into account the losses of the heat flux of solar radiation when passing through glass 1 and 2 by the reflection coefficients K_1 and K_2, in the first version the Stefan-Boltzmann equation is solved, as a result of which the temperature value of the absorber surface is obtained. In the second variant, the absorber temperatures were obtained taking into account convection.

1 Introduction

The city of Fergana is one of the cities of the Republic of Uzbekistan, in which the machine-building energy and petrochemical industries are developed. The population of the city has long-standing trade relations with the countries of the east and west. The population of the city and nearby settlements has household plots and gardens. In addition, the city is located in a region where in March the temperature already reaches +20 °C, and by the beginning of summer the temperature approaches +30 °C. In summer, during the daytime, the temperature is close to the 40-degree mark. From May to September, it rains very rarely in Fergana, the amount of precipitation begins to increase from October, while the daytime air temperature is still quite comfortable: +20 ... +23 °C.

In Fergana, given modern technologies based on clean energy, it is considered appropriate to introduce solar installations for drying local agricultural products, in particular, solar air heaters.

It is known [1] that in order to organize the correct operation of such collectors and create an optimal design of the SAH with high efficiency. It is necessary to know the temperature of the blackened surface that absorbs solar radiation and, as a result, the temperature of the heated air at the outlet of the collector. Obtaining such information is

* Corresponding author: s.s.sharofov@ferpi.uz

always associated with a large amount of experiments necessary to calculate these characteristics, as well as with the qualifications of researchers. Given the above, the authors of the article propose a fairly simple method for calculating these characteristics.

Consider the problem of determining the temperature of the air heater absorber t_w, for the climatic conditions of Fergana, with a horizontal collector and when solar radiation passes through double glass (Figure 1)

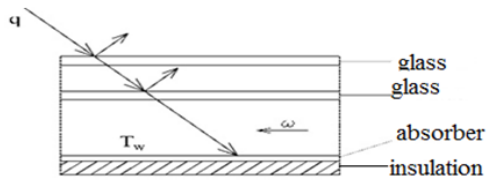

Fig. 1. Model of solar heating air heater without forced air flow.

We assume that in the considered short period of time the temperature of the absorber is constant and the heat loss through the insulation of the bottom of the collector is insignificant. Solar radiation passes through ordinary transparent colorless glass with a reflectance of 8%. Taking into account the losses of the heat flux of solar radiation when passing through glass 1 and 2 by the reflection coefficients K_1 and K_2, we write the heat flux balance equation in the form:

$$q \cdot K_1 \cdot K_2 = \varepsilon \cdot \sigma \cdot \left[\left(\frac{T_w}{100}\right)^4 - \left(\frac{T_{g.r.}}{100}\right)^4\right] \tag{1}$$

To select ε - the degree of emissivity of the black body, which is the absorber, let's assume that it is painted with black enamel paint ($\varepsilon = 0.8$).

$$K_1 \cdot K_2 = 0.85 \tag{2}$$

The formula for calculating the absorber temperature looks like this:

$$T_w = 100 \cdot \left[\frac{q \cdot K_1 \cdot K_2}{\varepsilon \cdot \sigma} + \left(\frac{T_{g.r.}}{100}\right)^4\right]^{\frac{1}{4}} \tag{3}$$

Where $\sigma = 5.67$ W/m^{2}K^4 - Stefan-Boltzmann constant.

2 Materials and methods

The city of Fergana is located at latitude of 400.23'.03". Table 1 shows the data of the total (direct and scattered) solar radiation arriving in July on the horizontal surface of the collector (Figure 1) with a cloudless sky, W/m^2 [1].

Table 1. Total solar radiation.

Latitude degrees north latitude 40^0	**Hours of the day**								
	5-6	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**
	98	252	443	628	761	878	928	928	878
	Hours of the day								
	14-15		**15-16**		**16-17**		**17-18**		**18-19**
	761		628		443		252		98

Table 2. Absorber temperature change during the hours of the day.

Hours of the day	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**
Total solar radiation	98	252	443	628	761	878	928
Absorber temperature $t_{ст}$ ^{0}C	40	60.3	81	98	109	118	121
Hours of the day	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**
Total solar radiation	928	878	761	628	443	252	98
Absorber temperature $t_{ст}$ ^{0}C	121	118	109	98	81	60.3	40

Figure 2 shows the change in temperature of the absorber during the hours of the day.

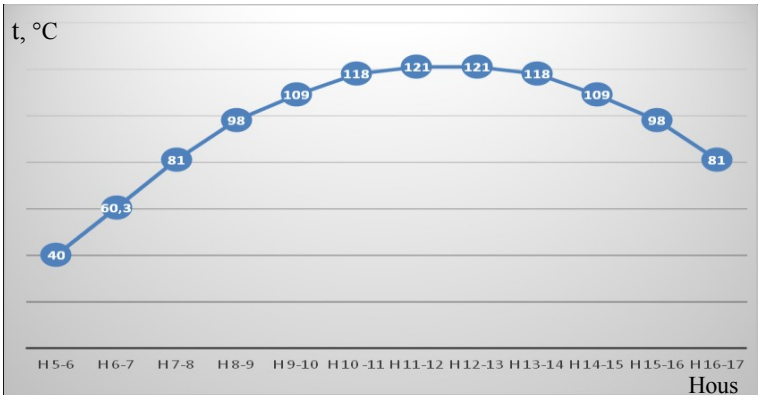

Fig. 2. Absorber temperature change during the hours of the day.

If air is supplied to the collector and forced convection is observed, then the heat transfer model in the collector will be written in the form (Figure 3)

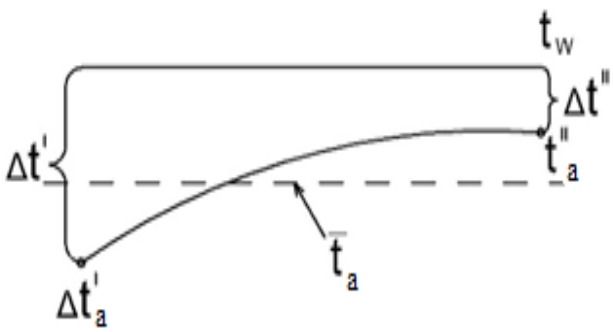

Fig. 3. Scheme of air temperature change during forced convection along the absorber surface.

$$q \cdot K_1 \cdot K_2 = \varepsilon \cdot \sigma \cdot \left[\left(\frac{T_w}{100}\right)^4 - \left(\frac{T_{g.r.}}{100}\right)^4\right] + \alpha[(\Delta t' - \Delta t'')/\ln((\Delta t'/\Delta t'')] \quad (4)$$

Equation (4) is non-linear and is solved by the method of successive approximations. Below are the calculations of equation (4) for $\alpha = 3$ W/m^2 °C.

The convective heat transfer coefficient α was determined from experiments, the meaning of which was as follows:

Heat transfer experiments were carried out in August 2022 in the city of Fergana at the experimental site of the Fergana Polytechnic Institute. The FSAH prototype had the following dimensions: length l = 1 m, width a = 0.5 m, height h = 0.05 m.

The experiments were carried out under daytime solar radiation. After the establishment of a quasi-stationary mode, with a given solar radiation flux, the temperature readings of the air flow at the heater inlet t' and outlet from it t'', as well as the wall t_{st} and the air flow rate G were recorded.

The determination of the heat transfer coefficients on the absorber was carried out after the establishment of a stationary temperature of the absorber wall, at a given density of solar radiation.

In each series of experiments, the heat flux was calculated by the formula:

$$Q = Gc_P\,[(t'' - t')], \tag{5}$$

Where G is the air flow rate, kg/s.

The air speed was calculated from the measured flow rate of the air coolant using the formula:

$$\omega = \frac{G}{\rho S} \tag{6}$$

Where $\rho S'$ are the density of the heat carrier and the cross section of the FSAH channel.

The Reynolds number was calculated as:

$$Re = \omega \cdot \frac{d_e}{\nu} \tag{7}$$

Where $d_e = 4 \cdot S/\Pi$ - equivalent channel diameter, m.

In order to verify the accuracy of the experiments, we first studied the heat transfer of a smooth-plate helio-receiving channel, in which at *Re*>2330 a turbulent flow regime was formed and which was approximated by the empirical formula:

$$Nu = 0.018 \cdot Re^{0,8} \tag{8}$$

3 Experimental error estimates

The instruments used in the heater circuit made it possible to directly measure the quantities with the following accuracy: when measuring air temperature with mercury thermometers with a division value of 0.5 ℃, the error was: $\Delta t = \pm 0.2^0$C.

The channel length *L* was measured with a metal ruler with a division value of 1 mm. those: ΔL=±0.5 mm.

The height of the air channel was measured with a caliper with an accuracy of ± 0.05 mm.

All other quantities obtained as a result of the experiment are derivatives of those directly measured in the experiment. Therefore, the errors for them should be calculated according to the formulas given below. Calculation of the heat transfer coefficient is carried out according to the formula:

$$\alpha = \frac{Q}{F_w \cdot (t_w - t_l)} \tag{9}$$

The maximum relative error in determining the heat transfer coefficient is:

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta Q}{Q} + \frac{\Delta t_w + \Delta t_l}{t_w - t_l} + \frac{\Delta F_w}{F_w} \tag{10}$$

The heat flow is calculated by the formula:

$$Q = GC_P\delta t \tag{11}$$

$$\frac{\Delta Q}{Q} = \frac{\Delta G}{G} + \frac{\Delta(\delta t)}{\delta t} + \frac{\Delta C_p}{C_p} \tag{12}$$

$$\frac{\Delta Q}{Q} = 1.42 + 1.22 + 0.53 = 3.17\%$$

Since the heat-releasing surface is equal $F = a \cdot \ell$, then

$$\frac{\Delta F}{F} = \frac{\Delta a}{a} + \frac{\Delta \ell}{\ell} == 4.4\%$$

$$\frac{\Delta t_{CT} + \Delta t_{Ж}}{t_C - t_{Ж}} = \frac{0.2 + 0.2}{90 - 30} = 6.6\%$$

The results are shown in Table 3. In Figure 4 shows the change in the temperature of the air leaving the collector, depending on the intensity of the total solar radiation

Table 3. Change in air temperature depending on the intensity of total solar radiation.

Hours of the day	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**
Total solar radiation	443	628	761	878	928	928
Outlet air temperature t'' °C	60	73	79	83	81	81

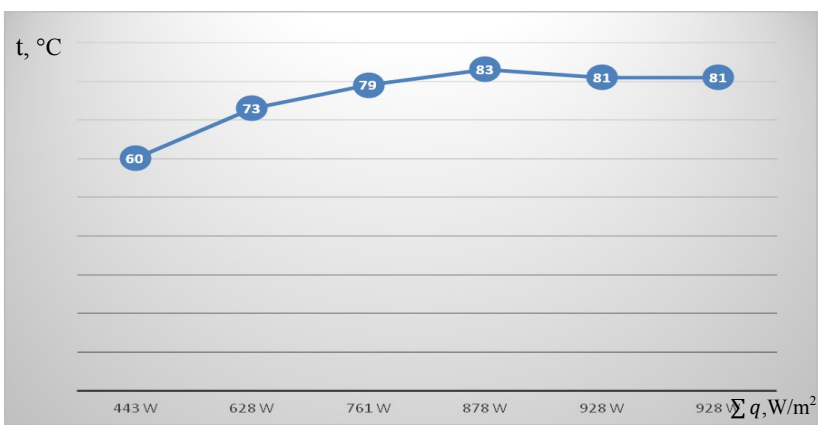

Fig. 4. Change in the temperature of the air leaving the collector, depending on the intensity of the total solar radiation.

4 Results and Discussion

The authors of the article for the first time for the climatic conditions of the city of Fergana obtained the calculated values of the temperatures of the blackened surface of the absorber, located horizontally flat solar air heater. The calculation method is based on the well-known Stefan-Boltzmann radiation calculation formula, but taking into account the loss of solar radiation intensity when passing through the transparent glass of the collector. The obtained values of the absorber temperatures are clearly high in the morning until almost noon and reach 120 °C, but then they tend to decrease.

5 Conclusion

The authors of the communication also obtained a computational mathematical model for determining the temperature values of the absorber for conditions of forced convection, and this model allows one to obtain the temperature of the heated air at the outlet of the solar air heater.

The problem of determining the temperature of the air heater absorber t_{st}, for the climatic conditions of the city of Fergana, with a horizontal collector and when solar radiation passes through double glass, is considered.

It is assumed that in the considered short period of time the temperature of the absorber is constant and the heat loss through the insulation of the bottom of the collector is negligible. Solar radiation passes through ordinary transparent colorless glass with a reflectance of 8%.

For the city of Fergana, which is located at a latitude of 400.23'.03”, the data of the total (direct and scattered) solar radiation entering in July on the horizontal surface of the collector under a cloudless sky were used, and using the Stefan-Boltzmann equation, the values of the absorber temperature were determined as in the condition absence, and in the presence of forced convection in the collector.

The value of the convective heat transfer coefficient was obtained by conducting experiments on a flat solar collector.

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