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Thermal efficiency of flat solar air heaters

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ABSTRACT:The article discusses the efficiency of flat solar air heaters, which are used in air heating systems of premises, drying plants. The disadvantages of such devices are low heat transferring them as consequences of large dimensions and weight.It is concluded in the flock that the increase in convective heat transfer in the channels of the heaters contributes to an increase in the efficiency of the heaters.Based on the analysis of the heat balance and heat transfer equations for a flat solar air heater.Formulas for the thermal efficiency and thermal performance of the heater are obtained.

KEYWORDS: Solar air heater, convective heat transfer, heat transfer intensification, thermal efficiency, thermal performance, heat exchanger model.

I.INTRODUCTION

In recent years, flat solar air-heating devices (FSAHD) began to play an important role in the preparation of heated atmospheric air with subsequent use in drying facilities, farms and in air heating systems of premises.

The merits of FSAHD can be attributed: the practical lack of corrosion, low requirements for tightness of FSAHD units, their use in any weather conditions.

The drawbacks of FSAHD can be attributed to the low intensity of heat transfer in the heat dissipating flat channels of devices consisting, as a rule, of a transparent and radiation-absorbing wall and, as a consequence, considerably the dimensions of the FSAHD.

A review of the literature on the problem of increasing the convective heat transfer in the channels of various heat exchangers [1-4] by using heat exchange intensifiers (protrusions, spherical depressions, diffuser-confusion channels, etc.) showed that rational use of heat exchange intensification can lead not only to an increase in the heat of hydraulic efficiency, but also to reduce the dimensions of the thermal device.

Analysis of the literature also showed that to date, in the theory of FSAHD, little attention is paid to their thermal and thermal energy efficiency [5-16].

As a design of the FSAHD selected for analyzing its efficiency, we choose a flat solar air heater in which a metal sheet with surface heat exchange intensifiers is used as an absorber of solar radiation (Fig. 1).

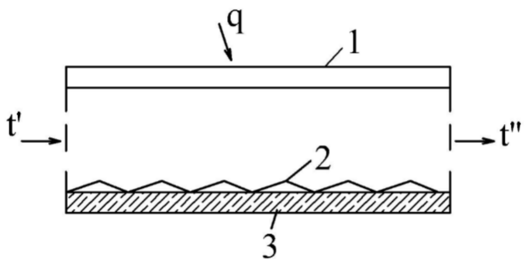

Fig.1. Flat solar air heater

1 - transparent coating, 2 - absorber, 3 – insulation

The diagram (Fig. 1) shows $t^{`}, t^{``}, t_w$ respectively the temperatures of incoming, outgoing air from the heater and absorber, q - density of incident solar radiation (W/m^2).

From the equation of the heat balance compiled for FSAHD in stationary conditions, we obtain

$$Q_1 = Q_2 + Q_3 \tag{1}$$

$Q_1 = GC_P(t_w - t^{`})$ – the maximum possible use of heat in FSAHD, W.

$Q_2 = GC_P(t^{``} - t^{`})$ – useful heat used in FSAHD, W

$Q_3 = GC_P(t_w - t'')$ – under-utilized heat in the FSAHD due to incomplete heat exchange between the absorber and the air flow W.

G,C_P –respectively, the flow rate (kg/s) and the heat capacity of kJ /kg°C of air.

The substitution of expressions into formula (1) gives

$$t_w - t' \approx (t'' - t') + (t_{\text{ст}} - t'') \quad (2)$$

The flow and heat capacity of air is considered constant

$$1 = \frac{t'' - t'}{t_w - t'} + \frac{t_w - t'}{t_w - t'} \quad (3)$$

Denoting by

$$\varepsilon = \frac{t'' - t'}{t_w - t'} \quad \text{and} \quad \varepsilon_{\text{пот}} = \frac{t_w - t''}{t_w - t'}$$

We get
$$1 = \varepsilon + \varepsilon_l \quad (4)$$

Or
$$\varepsilon = 1 - \varepsilon_l \quad (5)$$

We assume ε - thermal efficiency of FSAHD

ε_l –thermal losses in the FSAHD

Thus, Eq. (5) is the formula for the thermal efficiency of the FSAHD.

If $\varepsilon_l \to 0$ then $\varepsilon \to 1$ Therefore, for small thermal losses, ie, when the heat transfer is perfect, the thermal efficiency of the FSAHD tends to its maximum.

However, the thermal efficiency of the FSAHD is an incomplete characteristic of it, since the efficiency of the FSAHD should also be evaluated through its thermal performance. In such cases, methods are used to calculate the thermal performance of the SSHP based on a comparative analysis of the proposed and smooth-walled FSAHD. In this case, when comparing for the basic version, a solar air heater with a smooth-walled absorber is adopted.

If we use the theory of heat exchangers, the scheme for changing the air temperature when passing through the FSAHD will look like this.

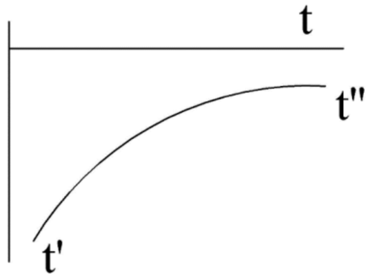

Fig.2. Changes in air temperature along the length of the FSAHD

The temperature head in the DSP can be defined as:

$$\Delta t = t_w - \frac{(t'' + t')}{2} = \frac{2t_w - (t'' + t')}{2} = \frac{(t_w - t'') + t_w - t'}{2} = \frac{(t_w - t')\left[\frac{t_w - t''}{t_w - t'} + 1\right]}{2} = \left(\frac{t_w - t'}{2}\right)[\varepsilon_l + 1] \quad (6)$$

Similarly, for a FSAHD with a smooth absorber, we obtain

$$\Delta t_{sm} = \frac{(t_w - t')}{2}[\varepsilon_l^{sm} + 1] \quad (7)$$

The thermal performance of a FSAHD can be defined as

$$Q = \alpha F \Delta t \quad (8)$$

Where $\alpha F \Delta$t are the coefficient of heat transfer from the absorber to the air (W/m^2°C), the surface of the absorber m^2, and the temperature head C^0

For FSAHD with a smooth absorber

$$Q_{sm} = \alpha_{sm} F_{sm} \Delta t_{sm} \quad (9)$$

$$\text{E} = \frac{Q}{Q_{sm}} = \frac{\alpha}{\alpha_{sm}} \frac{F}{F_{sm}} \frac{\Delta t}{\Delta t_{sm}} = \frac{Nu}{Nu_{sm}} \frac{[\varepsilon_l + 1]}{[\varepsilon_l^{sm} + 1]} \quad (10)$$

The formula (10) shows how much thermal performance of the FSAHD with the heat exchange intensifiers is higher than the FSAHD with a smooth absorber.

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To calculate the heat and heat energy efficiency according to formulas (5, 10), it is necessary to know the three parameters $t_w, t", t'$. However, in the design calculations, when the surface temperature of the absorber is known and the temperature of the incoming air in the FSAHD, the thermal efficiency of the FSAHD can be calculated by the theoretical determination of $t"$.

To this end, assume that the airflow in the cross section is a region consisting of a turbulized core and a narrow wall region in which the degree of turbulence greatly exceeds the turbulence of the core. According to the proposed scheme for the development of the flow in an absorber with artificial turbulization of the wall layer, we assume that in this region there is a sharp change in the velocity and temperature of the stream. Figure 3. shows the model of such a wall flow on the absorber.

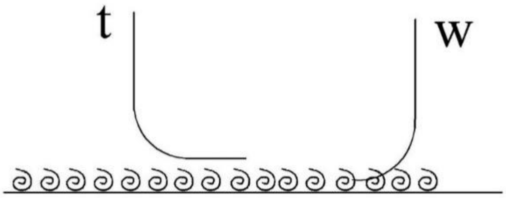


Fig. 3 Scheme of a two-layer wall flow t, W - temperature and velocity in the core of the flow.

At the output from the FSAHD, the core temperature of the stream is " . We apply the equation of the heat balance compiled for heat fluxes on the boundary wall region - the core of the flow, we obtain:

$$\alpha_{w.r}(t_w - t_b) = \alpha_c(t_b - t_c) \tag{11}$$

Here $\alpha_{w.r}, \alpha_c$ - are the coefficients of convective heat transfer of the wall region and the core of the flow, w/m^2 C^o.

t_b, t_c– temperature at the boundary of the wall region and the core of the flow.

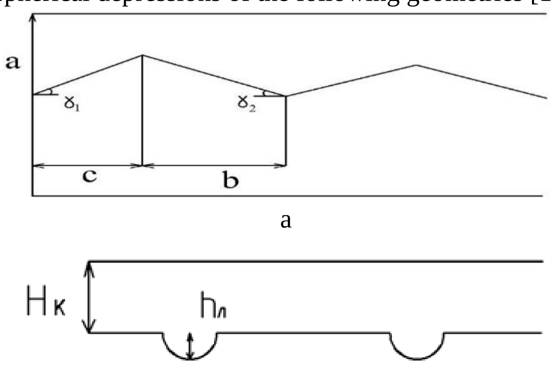
$$t_b = \left[t_w + \left(\frac{Nu_c}{Nu_{w.r}}\right)t^1\right]/[1 + \frac{Nu_c}{Nu_{w.r}}]$$

According to Fig.3, at the exit from the FSAHD$t" = t_b$

According to [1, 3], the use of absorbers with surfaces of the confusor-diffuser profile, as well as surfaces with spherical depressions (SS), for intensification of heat transfer in air flows with low Reynolds numbers (Re = 1000-2000), which correspond to real velocities in FSAHD, are promising.

Experimental studies have shown that the channels of the diffuser-confusor profile (Fig. 4) increase the heat transfer level by up to 2 times in comparison with the smooth channel, and the channels with the SS provide faster growth of heat transfer ($Nu / Nu_{sm} = 3$) in comparison with the increase in the hydraulic resistance ($\xi / \xi_{sm} = 1.8$). The optimal transverse dimensions of the depressions are ($h_l / h_{dk} = 0.21$) where h_l is the depth of the wells, h_{dk} is the channel diameter. The optimum relative dimensions of the depressions to the channel height are $h_l / H_k = 0.3$.

Here is an example of calculating the thermal and thermal energy efficiency of a FSAHD with a diffuser-confusor absorber and absorber with spherical depressions of the following geometries [1,3].



b

Fig. 4 Surfaces of diffuser-confuser type (a) and with spherical depressions (b).

The height of the helio-receiving channel is a = 47.7 mm, the ratio of the length of the diffuser to the length of the confuser is 5: 1 (b = 40 mm, c = 8 mm) [1]. It is also assumed that the wall temperature of the absorber C^0 is the air

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Vol. 5, Issue 6 , June 2018

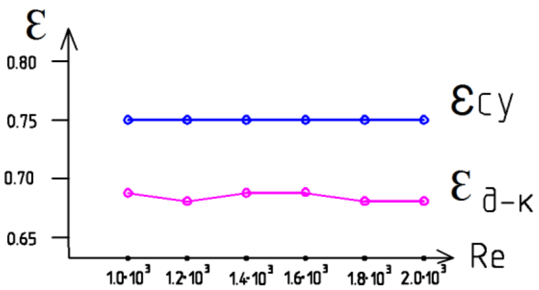
inlet temperature in FSAHD t^1 = 20 °C. Table 1 shows the calculation of the thermal efficiency ε, the thermal efficiency E of the FSAHD with an absorber of the diffuser-confuser type, and in Table 2 the calculations of ε, E for the FSAHD with an absorber consisting of spherical depressions.

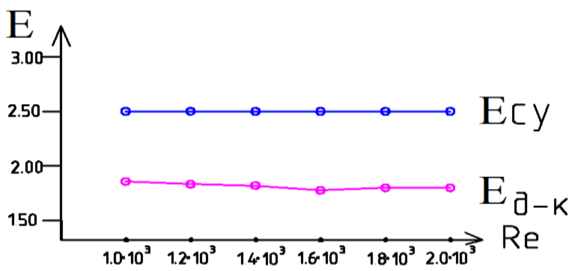
Table №1

№	Re	$\frac{Nu_c}{Nu_{w.r.}}$	t''	ε_1	ε	E
1	10^3	0,48	47	0,33	0,67	1,86
2	$1,2*10^3$	0,51	46,4	0,34	0,66	1,83
3	$1,4*10^3$	0,49	46,8	0,33	0,67	1,82
4	$1,6*10^3$	0,49	46,8	0,33	0,67	1,77
5	$1,8*10^3$	0,5	46,6	0,34	0,66	1,8
6	$2*10^3$	0,5	46,6	0,34	0,66	1,8

Table № 2

№	Re	$\frac{Nu_c}{Nu_{w.r.}}$	t''	ε_1	ε	E
1	10^3	0,33	50	0,25	0,75	2,5
2	$1,2*10^3$	0,33	50	0,25	0,75	2,5
3	$1,4*10^3$	0,33	50	0,25	0,75	2,5
4	$1,6*10^3$	0,33	50	0,25	0,75	2,5
5	$1,8*10^3$	0,33	50	0,25	0,75	2,5
6	$2*10^3$	0,33	50	0,25	0,75	2,5





II. CONCLUSIONSAND FUTURE WORK

1. A scheme for the exchange of convective heat energy in a plane FSAHD
2. A scheme for changing the airflow along the length of the FSAHD
3. The concepts of thermal efficiency and relative thermal performance of a flat FSAHD with heat exchange intensification were introduced, and formulas for their calculation were obtained.
4. A model of the near-wall current in a FSAHD with heat exchange intensifiers is proposed, and a formula for calculating the temperature at the output from the FSAHD is obtained.
5. Calculations of the thermal efficiency of a flat FSAHD with an absorber such as a diffuser-confuser and an absorber with an SS.
6. Calculations show a high efficiency of intensification of heat transfer and the need for its use to increase the thermal performance of the FSAHD.

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Umurzakova Muyassar is a Candidate of Technical Sciences. She conducted and completed numerous funded research projects and published more than 50 articles in various national and international conferences and journals