Study of a solar air heater with a heat exchanger – accumulator

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Abstract. The authors of the work presented a solar air heater for maintaining a constant temperature of heated air in drying plants and in air heating systems. The article discusses an experimental installation of a solar air heater was made and an insulated storage tank with a spiral-type heat exchanger for accumulating heated air was installed, additionally equipped with a hinged reflector parallel to the solar air heater, which is also an additional source of thermal energy of solar radiation, the results of an experimental study of the operating modes of the installation in natural and climatic conditions of Karshi. As a result of experimental studies, a high energy efficiency of a solar air heater was determined in the heating mode of heat carriers (air up to + 65 °C and waste oil up to + 75 °C) in June. The analysis of the heat balance of the developed installation is carried out. The influence of the main heat engineering parameters on the thermal power of the installation is analyzed.

1. Introduction

Burning fossil fuels leads to greenhouse gases (CO₂, SO₂, NOₓ), increased acid rain and air pollution, ozone depletion and global warming. The problem is exacerbated by the expected significant future increase in the demand for electricity and heat. The energy demand associated with air heating for different sectors is quite significant [1]. Solar air heaters have been designed to reduce the consumption of fossil fuels.

Today, in the world and in Uzbekistan, scientific research is underway aimed at creating power systems using solar low-grade installations in heat supply systems, taking into account the optimization of heat transfer processes necessary for the development of operational, technological and design parameters, control and control schemes that ensure the continuity of hydrodynamic, aerodynamic and thermal processes. [1-3]. Improving energy efficiency and developing new modern designs of solar air heating units, as well as improving the methodology of their hydrodynamic, aerodynamic and thermal calculations are one of the most important research tasks in this area [4]. At the same time, an increase in the efficiency of solar air heating plants based on an improved design of absorbers and an intensification of heat transfer processes due to turbulization of the coolant flow for
solar heat supply systems is relevant [5]. Until now, there is an acute problem of optimizing the contact surface of absorbers, taking into account effective heat transfer processes, as well as reducing economic costs due to the use of other types of energy in order to develop absorbers and solar air heaters with increased heat transfer.

Efficiency and their use in the heating system, in drying plants, remains unresolved.

In world practice, solar air heaters have been developed and investigated taking into account the increase in the heat transfer coefficient and energy efficiency, by providing an artificial absorber in solar air heaters [2-3].

One of the important tasks is to determine the efficiency of the heat accumulator for solar heat supply and air heating systems and it depends on the correct choice of material for heat accumulation, the degree of optimization of its capacity, the size of the elements and their layout, the speed of the coolant, location, and the possibility of its combination with building structures.

The energy efficiency problems of units operating on air heating units are described in the works of V.K. Migai, V.P. Isachenko, M.A. Mikheeva, M.V. Kirpichev, Ravish Kumar Srivastava, Raheleh Nowzari, Ho-Ming Yeh, Tong-Tshien Lin and other authors. The main thermotechnical characteristics of solar air heaters have been studied in the works of a number of authors, such as: O.S. Popel, J. Duffy, W. Beckman, V.A. Butuzov, B.B. Wurtz, J. Twidell, S.E. Freed, Foued Chabane, Noureddine Moumni, Zamry Ibrahim, Zahari Ibrahim, H. Kavoosi Balotaki, M.H. Saidi, and others [6-9].

This article investigates the influence of design, heat exchange, hydrodynamic and accumulation regime parameters on the energy efficiency of solar air heaters. The regularities of heat exchange processes in solar low-potential installations, as well as the methods of their calculation, were studied in the works of a number of famous scientists, such as: R.A. Zakhidov, R.R. Avezov, Sh. I. Klychev, A.A. Abdurakhmonov, G.N. Uzakov, N.R. Avezova, E.S. Abbasov and others [10].

Recently, solar air heaters (SAH) have been used for drying plants, in air heating systems and as a source of additional thermal energy. One block of the SAH module is enough to maintain a comfortable temperature in the spring-autumn period. The use of SAH allows to save consumption of traditional fuel (natural gas, coal and electricity) in winter.

Known developed solar collector Dibirov Ya.A. [11]. The proposed system consists of a housing with inlet and outlet holes for circulation of the coolant, a transparent coating and a heat and heat absorber installed in the housing parallel to the coating. The accumulator is made of heat-absorbing sections parallel to the absorber. The temperature regime of the coolant is provided by heat-absorbing sections, installed with the ability to move until they come into contact with each other and with the absorber.

The disadvantage of this system is that when the heat storage material is heated, only part of the total daytime solar radiation is used, which enters the surface of the absorber and is transferred to the heat accumulator only after the absorber is heated due to heat transfer from the lower surface (bottom) of the absorber [11].

2. Materials and methods

The purpose of this work is an experimental study of the operating modes of SAH with a heat exchanger-accumulator and an assessment of its energy efficiency in the southern natural and climatic conditions of the city of Karshi, Republic of Uzbekistan.

A solar air heater was created to maintain a constant temperature of the heated air and increase energy efficiency, which is provided by an additionally installed heat accumulator and a reflector.

We have developed a solar air heater that can be used in drying plants, air heating systems or space heating. An experimental solar air heater was created at the educational and scientific testing ground "Alternative energy sources" of the Department "Alternative energy sources" of the Karshi Engineering Economics Institute and is shown in Figure 1.

An insulated storage tank with a spiral heat exchanger is additionally installed in the solar air heater to accumulate the heat of the heated air, and is additionally equipped with a hinged reflector located in parallel with the solar air heater, which is also an additional source of thermal energy from solar
radiation. This will allow not only to increase the efficiency of the SAH unit, but also to increase the coverage of the heat load of the heat supply facility, as well as to increase the volume of heat energy.

Figure 1. Diagram of a solar air heater. (A is a general view of a solar air heater, B is a section):
1-glass, 2-heat-insulated body, 3-4- "pipe-in-pipe" device, 5-6-accumulator tank with a spiral-type heat exchanger, 7-oil channel for moving waste oil, 8-electric heater, 9-hinged reflector, 10 -valve, 11-exhaust pipe, 12-absorber.

The sun's rays, passing through the glass, are absorbed by the surface of the heat-absorbing panel, simultaneously heating the air entering through the lower end of the air heater body and the upper walls of the containers with the waste oil heat-accumulating substance. The heat absorbed by the waste oil is transferred by conduction mainly to the outer surfaces of the pipe-in-pipe device. The pipe-in-pipe device allows not only to heat the internal air located on the side of the heat-absorbing surface of the heat accumulator, but also the inner part of the storage tank with a spiral-type heat exchanger. The air heated in the "pipe-in-pipe" device on both sides of the heat-absorbing panel is continuously supplied directly to the consumer through the open tops of the storage tank with a spiral-type heat exchanger. During periods of direct sunlight, the consumer receives heated air at a constant temperature equal to that of the waste oil.

The electric heater is a backup heater and maintains a stable temperature regime in systems during cloudy days and at night.

In the experiments carried out, important thermophysical properties of heat carriers (air, waste oil) were adopted, which affect the heat transfer processes in the installation. Table 1 the thermophysical characteristics of coolants are presented [9].

Table 1. Thermophysical characteristics of heat carriers depending on temperature at atmospheric pressure.

| Heat carrier | \( t, ^\circ C \) | \( \rho, \text{kg/m}^3 \) | \( c_p, \text{kJ/(kg} ^\circ C) \) | \( \lambda, \text{W/m} ^\circ C \) | \( \mu \cdot 10^6, \text{Pa} \cdot \text{c} \) | \( \nu \cdot 10^6, \text{m}^2/\text{c} \) | \( a \cdot 10^6, \text{m}^2/\text{c} \) | \( \text{Pr} \) |
|--------------|---------------|----------------|----------------|-----------------|-----------------|----------------|----------------|-------|
| Air          | 20            | 1.205          | 1.005          | 0.0257          | 18.1            | 15.06          | 24.4           | 0.703 |
| Waste oil    | 20            | 880.3          | 1.666          | 0.1106          | 198.2           | 22.5           | 7.56           | 298   |

As can be seen from Table 1, the heat capacity of the waste oil is maximum 1.66 times that of air, and the thermal conductivity is 5.5 times that of air.

These indicators allow the maximum use of waste oil for the accumulation of thermal energy and as an accumulating substance.

For calculating the thermal efficiency of the SAH, the initial data are the following thermotechnical parameters: the ambient temperature, the value of the total solar radiation falling on the radiation-
receiving surfaces of the SAH, the time of the SAH operation, the flow rate of the coolant (air and waste oil), the initial temperature of the coolant, materials and geometrical dimensions of the SAH. Thermal calculation of the heat balance of the SAH was carried out according to the well-known method [7].

Theoretical studies are based on the methods of technical thermodynamics, solar engineering, the theory of heat and mass transfer, hydrodynamics and aerodynamics. Field studies were carried out on an experimental installation of a solar air heater with a heat accumulator and a computational experiment. The main structural element of the proposed system is SAH. To determine the parameters of the SAH, a heat engineering calculation was performed using the following procedure [8-9].

SAH is a combined version of an air and accumulation solar collector, in which air is simultaneously heated and heat is accumulated in the waste oil. The SAH efficiency factor \( \eta \), which is the ratio of the amount of useful energy received by air and waste oil in the SAH, to the amount of energy received from solar radiation on the surface of the SAH absorber, is determined by the formula [8-9]:

\[
\eta = \frac{Q_{usef} + Q_{ref} + Q_{ho}}{Q_r} = \frac{Q_{usef} + Q_{ref} + Q_{hwo}}{\frac{q_r}{\frac{F_{SAH}}{m^2}}} 
\]

where, \( Q_{usef} \) - useful energy, W; \( Q_{ref} \) - energy received by the receiver from the sun through the reflector, W; \( Q_{hwo} \) - heat transferred by waste oil in the lower channel of the SAH, W; \( Q_r \) - the amount of solar energy supplied to the surface of the SAH, W; \( \frac{q_r}{\frac{F_{SAH}}{m^2}} \) - the intensity of the total radiation on the surface of the SAH, \( \frac{W}{m^2} \); \( F_{SAH} \) - SAH radiation-receiving surface, \( m^2 \).

Useful heat energy (heat output) is equal to:

\[
Q_{usef} = G_w \cdot \rho_{air} \cdot c_p (t_{in2} - t_{out1}), \ W
\]

where, \( G_w \) - volumetric air flow, \( \frac{m^3}{sek} \); \( \rho_{air} \) - air density, \( \frac{kg}{m^3} \); \( c_p \) - specific isobaric heat capacity of air, \( \frac{Dj}{kg \cdot \circ C} \); \( t_{in2} \) and \( t_{out1} \) - air temperature at the inlet and outlet and SAH, °C.

The energy received by the receiver from the sun through the reflector can be determined by the equation [10-13]:

\[
Q_{ref} = R_{ref} \cdot A_{ref} \cdot E_{ref} \cdot F_{ref}, \ W
\]

where, \( E_{ref} \) - reflector mirror irradiance, \( \frac{W}{m^2} \); \( F_{ref} \) - reflector surface area, \( m^2 \); \( R_r \) -reflectivity of reflector mirror; \( A_{ref} \) - receiver absorption coefficient.

The heat transferred by the waste oil in the lower channel of the SAH can be determined by the equation [14-15]:

\[
Q_{hwo} = G_{hwo} \cdot c_{hwo} \cdot (t_{wo2} - t_{wo1}),
\]

Heat balance of SAH:

\[
Q_r = Q_{usef} + Q_{ref} + Q_{hwo} + Q_{lost},
\]

or:

\[
q_r F_{SAH} \cdot \alpha_a \cdot \tau + G_{tn} \cdot c_{hwo} \cdot (t_{wo2} - t_{wo1}) = Q_{usef} + Q_{ref} + Q_{hwo} + Q_{lost},
\]

where, \( \alpha_a \) - absorption capacity of the absorber, \( \tau \) - throughput of transparent enclosure (glass); \( Q_{lost} \) - losses of heat energy of SAH, W.

Heat losses are determined by the formula [16]:
\[ Q_{\text{lost}} = Q_{\text{conv}} + Q_{\text{rad}} + Q_{\text{cond}}, \text{W} \] (7)

where, \( Q_{\text{conv}} \) – heat energy losses through convective heat exchange, \( Q_{\text{rad}} \) – value of radiation losses, \( Q_{\text{cond}} \) – heat energy losses through thermal conductivity, \( \text{W} \).

If we assume that \( Q_{\text{lost}} \) is equal to the total heat transfer loss, then [14-17]:

\[ Q_{\text{lost}} = Q_0, \] (8)

or:

\[ Q_{\text{lost}} = k \cdot F_{\text{total}}(t_{\text{awer}} - t_{\text{en}}), \] (9)

where, \( k \) – heat transfer coefficient, \( \frac{W}{m^2\cdot\degree C} \); \( F_{\text{total}} \) - total area of heat exchange with the environment, \( m^2 \); \( t_{\text{awer}} \) - average air temperature inside the SAH, \( \degree C \); \( t_{\text{en}} \) - environment temperature, \( \degree C \).

3. Results and discussion

Computational and experimental studies to determine the heat engineering parameters of SAH were carried out according to the well-known technique [18].

In the experiments, the total intensity of solar radiation, wind speed, outside air temperature, waste oil temperature, air temperature at the inlet and outlet of the SAH, and air consumption were measured. The total intensity of solar radiation was measured with an actinometer. The total intensity of solar radiation was measured with an actinometer MAC SOLAR (Germany), the air velocity was an anemometer. To measure the temperature, we used XK thermometers in the KSP-4 set.

The results of the experimental and computational studies in the city of Karshi of the Republic of Uzbekistan (in the geographical latitude of the area – 39\(^\circ\)) are shown in figure 2.

![Figure 2](image.png)

**Figure 2.** The density of the absorbed flux of solar energy for a surface installed at an angle of 39\(^\circ\) to the horizon on clear days of summer months in the city of Karshi, Republic of Uzbekistan.

In June 2020, the maximum level of solar radiation was recorded for the entire experimental research period. These results of computational and experimental studies are presented in table 2 and figure 3.
Table 2. Results of an experimental study of SAH in the mode of heating air and waste oil (July 2020).

| The local time | Inlet air temperature, $t_{out1}$, °C | Air flow, $G_{air}$, m³/s | Outlet air temperature, $t_{in2}$, °C | Waste oil temperature, $t_{hwo}$, °C | The intensity of the total solar radiation flux on the SAH area, $Q_r$, W |
|----------------|--------------------------------------|---------------------------|-------------------------------------|-----------------------------------|----------------------------------|
| 5:00           | 18                                   | 0,04                      | 20                                  | 21                                | 200                             |
| 6:00           | 20                                   | 0,04                      | 25                                  | 26                                | 250                             |
| 7:00           | 23                                   | 0,04                      | 30                                  | 34                                | 450                             |
| 8:00           | 25                                   | 0,04                      | 36                                  | 39                                | 550                             |
| 9:00           | 27                                   | 0,04                      | 38                                  | 44                                | 730                             |
| 10:00          | 30                                   | 0,04                      | 44                                  | 46                                | 800                             |
| 11:00          | 34                                   | 0,04                      | 52                                  | 53                                | 930                             |
| 12:00          | 36                                   | 0,04                      | 58                                  | 65                                | 100                             |
| 13:00          | 40                                   | 0,04                      | 60                                  | 73                                | 1100                            |
| 14:00          | 44                                   | 0,04                      | 65                                  | 78                                | 1150                            |
| 15:00          | 42                                   | 0,04                      | 62                                  | 75                                | 1100                            |
| 16:00          | 38                                   | 0,04                      | 60                                  | 70                                | 950                             |
| 17:00          | 32                                   | 0,04                      | 51                                  | 65                                | 750                             |
| 18:00          | 27                                   | 0,04                      | 45                                  | 55                                | 450                             |
| 19:00          | 22                                   | 0,04                      | 40                                  | 48                                | 150                             |
| 20:00          | 20                                   | 0,04                      | 28                                  | 37                                | 100                             |
| 21:00          | 18                                   | 0,04                      | 24                                  | 27                                | 20                              |
| 22:00          | 16                                   | 0,04                      | 22                                  | 22                                | 15                              |

Figure 3. The graph of the temperature change of the coolant.

Figure 3 shows a graph of the temperatures of the coolant at the inlet and outlet of the SAH and in the storage tank, as well as the graph of the temperature change of the used oil in the conditions of the city of Karshi, Republic of Uzbekistan.
4. Conclusion
As a result of experimental studies, the main thermal engineering parameters of the experimental installation and the operating modes of the SAH with a heat exchanger-accumulator were substantiated.

The experiments and analysis of the data presented in Table 1 and Figure 2 show that the proposed SAH with a heat exchanger-accumulator will provide simultaneous heating of the supply air and waste oil up to 65-75 °C.

The degree of provision of thermal loads of drying units with the help of sah was up to 85% per day.

The technical and economic efficiency of the presented device lies in the fact that the solar air heater is easy to use - it quickly heats up and accumulates heat, can be easily removed from the case and the duration of their use in heating premises for various purposes is significant.

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