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Evaluation of the exergy efficiency of the solar air collector with turbulators

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ABSTRACT: Solar air collectors are widely used because they are convenient to use solar energy, cheap and easy to operate. A large number of studies are being conducted on increasing the useful energy and exergy obtained based on the acceleration of thermal-hydrodynamic processes in solar air collectors. In this research work, a review of the research conducted on the determination of effective and exergetic UWC values in solar air collectors, the procedure for calculating the effective and exergetic UWC, as well as the results of the changes of the effective and exergetic UWC in six different models proposed by the authors are presented. These results can be used in the development of solar air collectors with high energetic and exergetic efficiency.

I. INTRODUCTION

Exergy is a property of a thermodynamic system or energy flow, and is determined by the maximum amount of work that can be obtained in the interaction of a system receiving external energy with the environment until full equilibrium is established, that is, the system is the maximum useful working potential and is a measure of useful energy. Therefore, exergy is used to develop the most efficient system. Exergetic analysis is a useful method in the design and operation of SACs when considering the optimal use of energy in SACs. Many researchers have conducted studies devoted to the exergetic study of SAC. Energetic and exergetic efficiency of SACs with different smooth absorbers Karsley [1] identified by. SAC performance parameters to achieve maximum exergetic efficiency in SAC with smooth absorber Gupta and Kaushik [2] optimized by. Esan [3] conducted an experimental study of the energy and exergetic efficiency of two-way SAC with a smooth absorber and ribs in a wide range of operating conditions. Nwosu [4] used exergy-based optimization to determine the dimensions of edged fins in the design of the SAC absorber and showed that the high efficiency of the optimized fin significantly increased the heat absorption in the SAC. Singh et al [5] have analyzed the exergetic SAC with a V-shaped rib in the absorber. According to the authors, the use of exergetic analysis was considered the most optimal solution for the design of SACs with wavy fins. The exergetic UWC reached the maximum value at the optimal parameters of the continuous V-shaped rib for a given Reynolds number. Based on the analysis of the above-mentioned literature, we will analyze the exergy of SAC with a turbulizer. It is known that in exergetic analysis, pressure loss is taken into account, air is considered as an ideal gas, the change of kinetic and potential energy is very small, and the process and flow are assumed to be stable. Potgieter and others [6] when conducting a pilot numerical study of hybrid SAC, the average efficiency of SAC varied from 23 to 83%. Wang and others [7] studied SAC with S-shaped ribs in the absorber. Various parameters of the corrugation were studied: the distance between the ribs, the width of the rib, the width of the rib gap, the height of the channel, the intensity of solar radiation and the speed of the air flow. According to the results, the thermal UWC value of the modified SAC was 48% higher than that of the normal SAC. Sivakandhan and others [8] proposed a new hybrid channel SAC with inclined ribs. In the new design, when the camber pitch is 8, the relative arc angle is 0.5, the camber height is 0.021, and the air mass consumption is 0.045 kg/s, the SAC has the maximum UWC and is 80.1% reached. As can be seen from the analysis of the literature presented above, studies on determining the values of effective and exergetic UWC in turbulizer SACs have not been carried out enough. Taking this into account, in this research work, effective and exergetic UWC values of turbulizer SACs were determined and compared with each other.

II. MATERIALS AND METHODS

The effective UWC of SAC is defined as follows [9]:

$$\eta_{ef} = \frac{(Q_u - N)}{SA_{SAC}} \tag{1}$$

where Q_u is the useful energy obtained during the operation of SAC:

$$Q_u = mc_p(t_o - t_i) \tag{2}$$

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where c_p is specific heat capacity of air, J/(kg·°C); t_i, t_o-temperatures of air inlet and outlet of the SAC, °C, m-mass consumption of air flowing through the SAC, kg/s:

$$m = \rho V A_{c.t} \tag{3}$$

where ρ is air density, kg/m^3; V-average speed of air, m/s; $A_{c.t}$-surface of the cross-sectional area of the air inlet hole, m^2.

The total energy consumption (N) in SAC is equal to the energy consumption of the fan (P_{fan}):

$$N = P_{fan} t \tag{4}$$

$$P_{fan} = \frac{m\Delta P}{\rho \eta_{fan}} \tag{5}$$

where m-mass consumption of air, kg/s; ΔP-total pressure drop in SAC, Pa; ρ-air density; η_{fan}- fan's UWC, usually $\eta_{fan} = 0{,}7$.

The exergetic balance for SAC can be written as:

$$Ex_{in} - Ex_{out} = Ex_{dest} \tag{6}$$

where Ex_{in}-exergy input to SAC (exergy input power); Ex_{out}-exergy output from SAC (exergy output power); Ex_{dest}-exergy loss (exergy destruction).

The exergy input power to the SAC includes the exergy coefficient of solar radiation intensity [10]:

$$Ex_{in} = I_{ab} A_{ab} \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \tag{7}$$

where I_{ab}-solar radiation energy absorbed into the absorber, W/m^2; A_{ab}-absorber surface area, m^2; $T_a = 27$°C-ambient temperature; $T_s = 5727$°C-solar temperature [11].

Exergy output power from SAC:

$$Ex_{out} = mc_p(T_o - T_i)\left(1 - \frac{T_a}{T_o}\right) \tag{8}$$

The exergetic UWC of the SAC is defined as the ratio of exergy actual output power to actual input power:

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} \tag{9}$$

III. RESULTS AND DISCUSSION

The fan power values determined from the useful energy obtained in SAC with smooth absorber and turbulizer and the value of pressure lost to drive air and the effective UWC values of SAC with smooth absorber and turbulizer were determined using (1). In this case, the speed of the air flow changed in the range of 4...20 m/s, the solar radiation intensity was 1000 W/m^2, and the outside air temperature was assumed to be 27°C. The effective UWC values determined for each model were compared with the effective UWC value of the smooth absorber SAC. Each model was also compared with each other. The results of the change of the effective UWC value at different air speeds are shown in Fig. 1.

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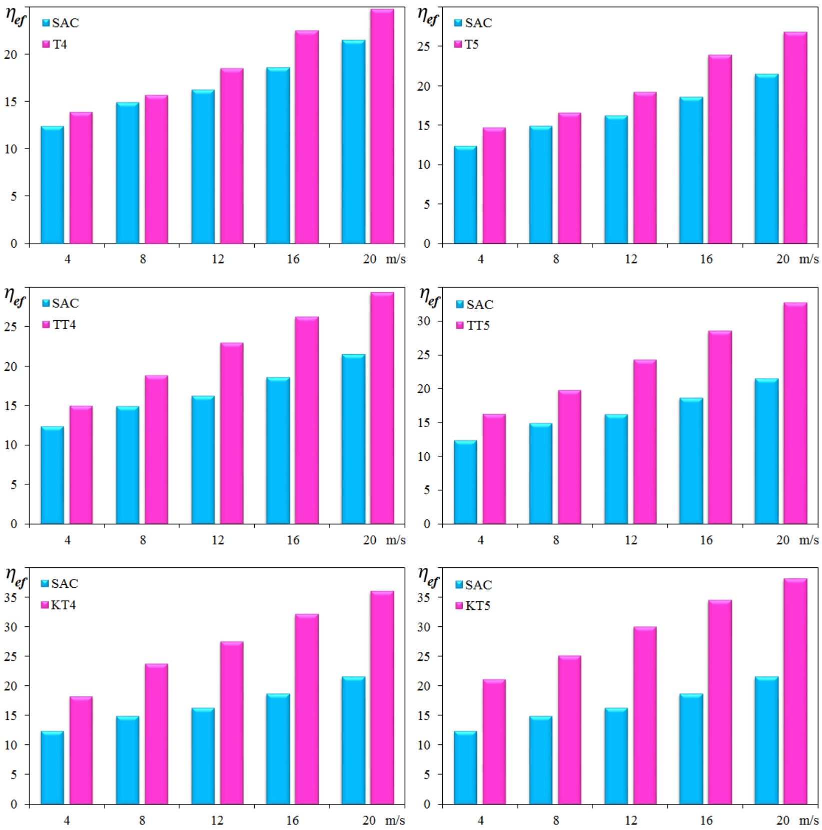

Fig.1. Results of changes in effective UWC value in six models.

From the results presented in Fig. 1 above, it can be seen that the value of increasing the effective UWC was different in all models and increased with increasing air speed. The effective UWC values at air velocities of 4, 8, 12, 16, and 20 m/s were as follows: 12.4, 14.9, 16.2, 18.5, and 21.5 in SAC with smooth absorber; 13.9, 15.7, 18.5 22.4 and 24.7 in the T4 model; 14.7, 16.6, 19.2, 23.9, and 26.8 in the T5 model; 14.9, 18.8, 22.9, 26.2 and 29.3 in the TT4 model; 16.3, 19.8, 24.2, 28.5 and 32.7 in the TT5 model; 18.2, 23.7, 27.4, 32.1 and 35.9 in the KT4 model; 21.1, 25.1, 29.9, 34.5 and 38.1 in the KT5 model. Compared to the average values of the effective UWC, the effective UWC value is 1.14 times in the T4 model, 1.21 times in the T5 model, 1.34 times in the TT4 model, 1.46 times in the TT5 model, 1.46 times in the KT4 model, compared to the smooth absorber SAC. It was found to be 64 times higher and 1.78 times higher in the KT5 model. The results of each model comparison are shown in Fig.2.

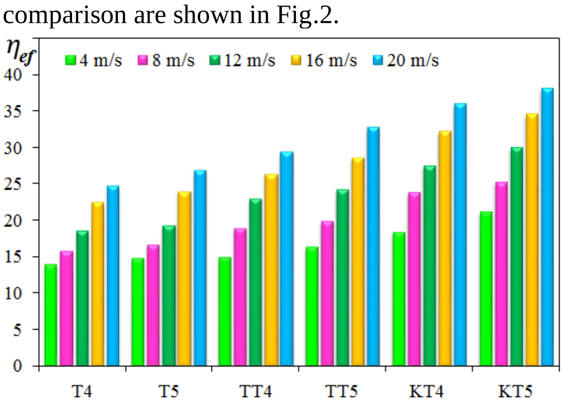

Fig.2. Results of comparison of effective UWC values of six models.

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From the comparison results of the effective UWC values of the six models presented in Fig.2 above, it can be seen that the effective UWC value of the KT5 model is the highest. It was found that the effective UWC value of KT5 model is 1.56 times higher than T4 model, 1.47 times higher than T5 model, 1.32 times higher than TT4 model, 1.22 times higher than TT5 model and 1.08 times higher than KT4 model.

Exergetic UWC value of SAC with smooth absorber and turbulizer was determined based on the expressions (1)-(4) given above. In this case, the speed of the air flow was 4...20 m/s, and the solar radiation intensity was 1000 W/m^2. The exergetic UWC values determined for each model were compared with the exergetic UWC value of the smooth absorber SAC. Each model was also compared with each other. The results of changing the exergetic UWC value at different air speeds are shown in Fig.3.

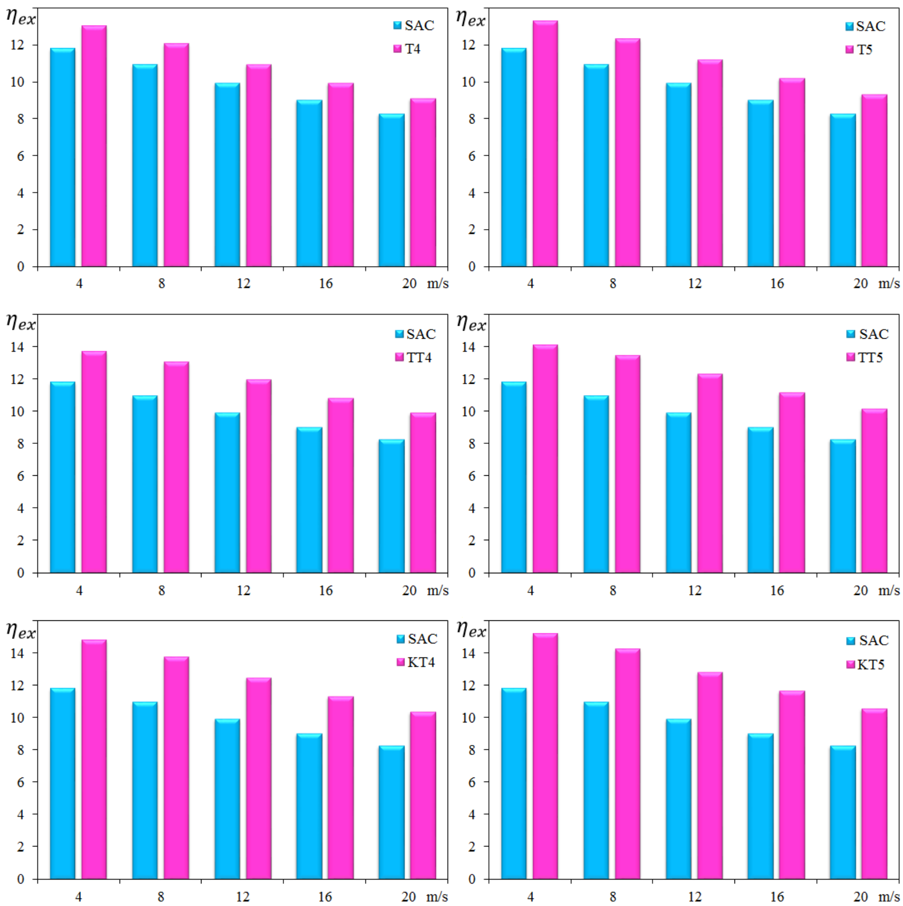

Fig.3. Results of change of exergetic UWC value in six models.

As can be seen from the results presented in Fig.3, the value of exergetic UWC decreased with increasing air velocity in SAC with smooth absorber and turbulizer. Exergetic UWC values were as follows when the air velocity was 4, 8, 12, 16, and 20 m/s: 11.8, 10.9, 9.9, 9.0, and 8.3 in SAC with a smooth absorber; 13.0, 12.0, 10.9, 9.9 and 9.1 in the T4 model; 13.3, 12.3, 11.2, 10.2 and 9.3 in the T5 model; 13.7, 13.0, 11.9, 10.8 and 9.9 in the TT4 model; 14.1, 13.4, 12.3, 11.1 and 10.2 in the TT5 model; 14.8, 13.7, 12.4, 11.3 and 10.3 in the KT4 model; 15.2, 14.2, 12.8, 11.6 and 10.6 in the KT5 model. Compared to the average values of exergetic UWC, the value of exergetic UWC is 1.10 times in T4 model, 1.13 times in T5 model, 1.19 times in TT4 model, 1.22 times in TT5 model, 1.22 times in KT4 model, compared to SAC with smooth absorber. 25 times and KT5 was found to be 1.29 times higher in the model. The results of each model comparison are shown in Fig.4.

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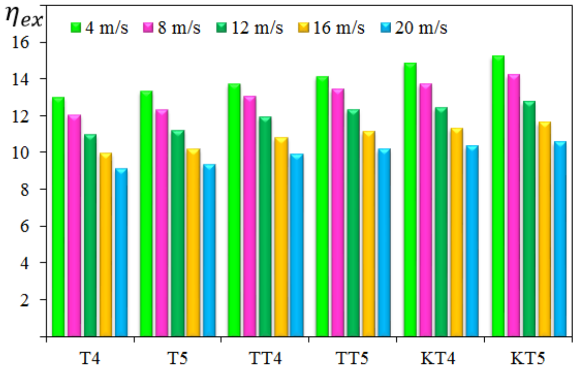

Fig.4. Results of comparison of exergetic UWC value of six models.

From the comparison results of the exergetic UWC values of six models presented in Fig.4, it can be seen that the exergetic UWC value is the smallest in the T4 model and the highest in the KT5 model. It was found that the exergetic UWC value of the KT5 model is 1.17 times higher than the T4 model, 1.14 times higher than the T5 model, 1.09 times higher than the TT4 model, 1.05 times higher than the TT5 model, and 1.03 times higher than the KT4 model.

The effect of air flow rate on the effective (y-axis on the left) and exergetic UWC characteristics is shown in Fig.5. Effective UWC increased and exergetic UWC decreased with increasing airflow rate in all models.

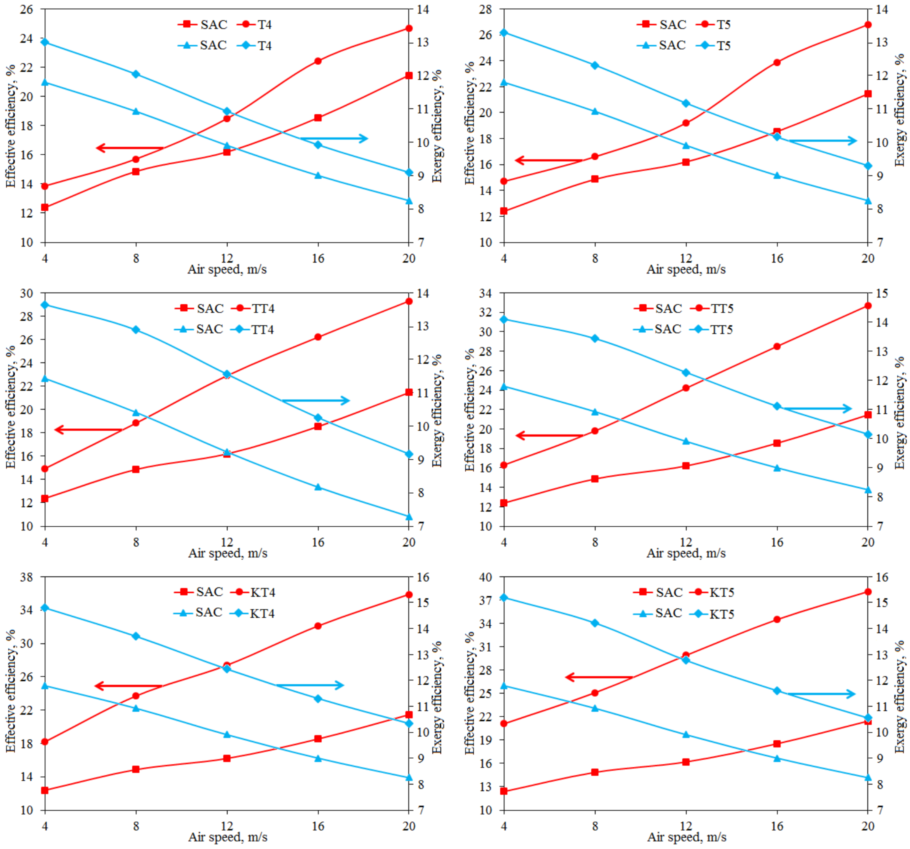

Fig. 5. Results of changes in effective and exergic SACs.

Comparing the effective and exergetic UWC at different air flow velocities, it can be seen that the highest values of UWC in all models are between 8 and 12 m/s of air flow velocity. The maximum point of intersection of the lines represents the best effective and exergetic UWC values. These values are as follows: effective UWC 16.25% and exergetic UWC

9.83% for SAC with smooth absorber, effective UWC 18.75% and exergetic UWC 10.89% for model T4, effective UWC 20.67% and exergetic UWC for model T5 UWC 10.91%, effective UWC 22.92% and exergetic UWC 11.74% for model TT4, effective UWC 25.09% and exergetic UWC 12.04% for model TT5, effective UWC 27.11% for model KT4 and exergetic UWC is 12.52%, effective UWC is 29.38% and exergetic UWC is 12.89% for the KT5 model. The maximum exergetic UWC value when the air flow speed changes in the range of 4...20 m/s is 13.0% in the T4 model, 13.3% in the T5 model, 13.7% in the TT4 model, 14.1% in the TT5 model, 14.1% in the KT4 model ,8 and 15.2% in the KT5 model, and it can be seen from the exergetic analysis of SAC with smooth absorber and turbulizer that the exergetic efficiency is the highest in the KT5 model.

IV. CONCLUSION

When the air flow speed varies in the range of 4...20 m/s and the solar radiation intensity is 1000 W/m^2, the average value of the effective UWC is the maximum in the KT5 model, 1.56 times compared to the T4 model, It was found to be 1.47 times higher than the T5 model, 1.32 times higher than the TT4 model, 1.22 times higher than the TT5 model, and 1.08 times higher than the KT4 model.

The exergetic efficiency of SAC with smooth absorber and turbulizer is maximum in KT5 model compared to other models, 1.17 times compared to T4 model, 1.14 times compared to T5 model, 1.09 times compared to TT4 model, 1.05 times compared to TT5 model and KT4 it was found to be 1.03 times higher than the model.
Effective and exergetic UWC was maximum for all models in the air flow velocity range of 8...12 m/s, it was found to be the highest in model KT5 and effective UWC was 29.38% and exergetic UWC was 12.89%.

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