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Research Article

Energy and exergy analysis of an enhanced solar CCHP system with a collector embedded by porous media and nano fluid

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ABSTRACT

The low efficiency of Collectors that absorb energy can be mentioned as one of the drawbacks in solar cogeneration cycles. In the present study, solar systems have been improved by adding porous media and Nanofluid to collectors. One advantage of using porous media and nanomaterials is to absorb more energy while the surface area is reduced. In this study, first, solar collectors are enhanced using 90% porosity copper in solar combined cooling, heating and power systems (SCCHP). Second, different percentages of CuO and Al_2O_3 nano-fluids are added to a flat plate and parabolic collectors to enhance thermal properties. Simulations are performed in different modes (simple parabolic collectors, simple flat plate collectors, improved flat plate collectors, parabolic collectors with porous media, and flat plate and parabolic collectors with different density of CuO and Al_2O_3 nanofluids). A case study is investigated for warm and dry regions with mean solar radiation Ib = 820 w / m2 in Iran. The maximum energy and exergy efficiencies are 60.12% and 18.84%, respectively, that is related to enhanced parabolic solar collectors with porous media and nanofluids. Adding porous media and nano-fluids increases an average 14.4% collector energy efficiency and 8.08% collector exergy efficiency.

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INTRODUCTION

These days' energy plays an important role in the economic growth of human societies. Among the types of energy consumed by mankind, solar energy can be considered as the most abundant one. Increasing the rate of energy consumption in different countries along with low efficiency of energy production, transmission and distribution system, makes a new system to generate simultaneously electricity, heating and cooling as an essential solution to be widely used.

Cogeneration using renewable energy has been started four decades ago, Cogeneration reduces the emission of

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greenhouse gasses and other pollutants along with increasing efficiency and reducing fuel consumption. Building energy consumption mainly involves electricity needed for lighting and home appliances, heating and cooling of building interior and hot water. Domestic usage contributes to an average of 35% of the world's total energy consumption [1]. In order to minimize fossil fuel consumption, clean and renewable sources are being used. Having more than 2900 annual sunshine hours, and high solar radiation, Iran is among good countries for making use of solar energy [2]. Annual sunshine hours have a crucial effect on solar systems' performance. Because of the availability of free energy sources, the use of cogeneration systems on the basis of renewable energies is notably taken into consideration. Cogeneration production cycles based on solar, wind, biomass, etc. energies are widely used in remote areas that are far from energy carrier lines. Since renewable energies are not always available, applying combined cogeneration cycles (wind-solar, biomass-wind, and biomass-solar, etc.) is a good approach to solve the issue. Due to the availability of solar energy in all areas, these collectors can be used to obtain the driving power required for the cogeneration production cycle. Solar energy is the main source of energy in renewable applications. For selecting a suitable area to use solar collectors, annual sunshine hours, the number of sunny days, minus temperature and frosty days and the windy status of the region are of great importance [3].

The methods for increasing the efficiency of solar collectors are divided into two categories. The first category is to increase the collector energy absorption by physically improving the absorbent tubes, which include adding internal and external fins [3], adding porous materials into absorbent tubes [4]. The use of porous materials has grown vastly over the past two decades. In all cases, the use of porous materials improves absorption [5], and adding physical velocity reducers to generate turbulence flow in the collectors (using networks of Carbon fiber) [6]. The second category is the increase of absorbed energy by the working fluid. To optimize the solar collectors, the addition of nano particle, absorbing salts etc. [6], are appropriate approaches. Porous materials, especially porous foam, are widely used in solar systems, such as reactors and solar collectors. Due to the high contact surface area, porous media are appropriate candidates for solar collectors [7]. A solar collector is an apparatus able to collect the solar irradiation and transmit heat to a working fluid which will transport it towards zones need to be heated [8]. Solar collectors operate in a variety of temperatures. Operating range temperatures of flat plate solar collectors, evacuated tube collectors, and parabolic solar collectors are 20–80°C, 50–200°C, and 70-300°C respectively [9–10]. A number of researchers investigated solar system performance in accordance with the first and second laws of thermodynamics. Zhai, Dai [11] reviewed the performance of a small solar-powered system in which the energy efficiency was 44.7% and the electrical efficiency was 16.9%. Wang, Dai [12] attempted to optimize a cogeneration solar cooling system with a Rankine cycle and ejector to achieve the maximum total system efficiency of 55.9%. Jing et al. analyzed a building in which a solar cogeneration system with auxiliary heaters produced electrical, cooling, and heating power. The maximum energy efficiency in their work was reported 46.6% [13]. Temir and Bilge [14] analyzed the exergy and exergy economics of a cogeneration cycle with the reciprocating engine and prime mover. Various optimization methods have been used to improve the cogeneration system, minimum system size and performance, such as genetic algorithm [15].

Kleinstreuer and Chiang [16] have solved the thermal and fluid transfer equations in a flat plate collector covered by porous material and compared its thermal efficiency with a conventional collector. Their research results showed that the solar collector with porous media has higher absorption and thermal stability. Numerical studies of free displacement in the walls of solar collectors covered by porous media have been conducted by Mbaye and Bilgen [17]. porous medium and stated that geometric factors are one of the main parameters in the performance of the solar collectors' wall.

Hirasawa, Tsubota [18] empirically investigated the effect of using porous media to reduce thermal waste. They placed the high-porosity metal foam on top of the collector, and observed that thermal waste decreased by 7% due to natural heat transfer. Hassan, Abdul-Ghafour [3] performed a numerical study of the thermal performance of a solar collector column, with numerical simulations, solving the governing equations (continuity, waves and energy) in a smooth regime using FLUENT software. The effect of flow on the temperature distribution of flat collectors was simulated by placing torsion strips with the rotational ratio of 3 or rectangular fins around the collector tube and compared with a flat collector in a discharge of 100 liters per hour. The results indicated that the use of torsion strips in the outer tubes of the collector makes 10% increase in input energy.

Many researchers study the efficiency improvement of the collector by changing collector's shapes or working fluids. However, the most effective method and the latest technology is the nanofluids application in the solar collector as working fluid in the place of conventional fluids. The improved flat plate collector with porous and nano-fluid materials was investigated by Jouybari, Saedodin [19]. In this experimental study, the efficiency increases up to 8.1% was achieved by adding nano-fluid in a flat plate collector. In this research, by adding porous materials to the solar collector, collector efficiency increased to 92% in low mass flow rate and the Nusselt number was obtained equal to 237. The use of porous media in solar collectors increased the efficiency of 20 to 70% in the low regime. Subramani, et al.[20] analyzed the thermal performance of the parabolic collector with Al_2O_3 nano-fluid. They conducted their experiments with Reynolds number 2401 to 7202 and mass flow rate 0.0083 to 0.05 kg/s. The maximum efficiency enhancement of the experiment was 56% obtained at 0.05 kg/s mass flow rate.

Yousefi, Veysi [21] studied the Effects of aluminum Nano-fluid on performance on a solar flat plate collector indicated that by increasing the concentration Nano-fluid up to 0.2%, the collector power will rise up to 28%. Tyagi, Phelan [22] investigated the effects of different parameters on the efficiency of nanofluid based direct absorption solar collector in low temperature, where the working fluid is a mixture of water and Al_2O_3. Their results of variation of collector efficiency as a function of the particle volume fraction (%), in range of 0.1% to 5% showed that, the efficiency rises for low values of nanoparticles' volume fraction and for the magnitude higher than 2% it remains constant. Shojaeizadeh, Veysi [23] investigated the exergy efficiency of flat plate solar collector using Al_2O_3/water nanofluid and exergy efficiency increased maximum of about 0.72% than pure water. Tiwari, Ghosh [24] showed the Thermal performance of solar flat plate collectors for water by different Nano fluids investigated. The result indicated that, using 1.5% (optimum) particle volume fraction of Al_2O_3 nano fluid as an absorbing medium cause the thermal efficiency enhance up to 31.64 %. Many researchers study the efficiency improvement of the collector by changing different components or equipment or design as well as the setting of solar collectors. However, the most effective method and the latest technology is the nanofluids application in the solar collector as working fluid in the place of conventional fluids. Most experience showed that CUO and Al_2O_3 nanofluids with less than 0.6% percent solution are used in the investigation on the solar collectors at low temperatures and discharges [25].

In other studies, researchers investigated some other methods in the field of solar cogeneration cycles such as making use of hybrid collectors, other fluids (like salts, oils. etc.), and genetic algorithms to enhance cycle efficiency. Effect of each porous media and nanofluids on collectors solely have already been investigated in papers but solar cogeneration system with a collector both embedded by Porous media and nanofluid to enhance the efficiency of solar collectors based cogeneration cycles was never taken into consideration. In the present study parabolic and flat plate collectors in four following cases are compared to each other in the solar cogeneration cycle: conventional, embedded by porous media, embedded by nanofluids, and embedded both by porous media and nanofluids. In this research, the amount of energy and exergy of the solar cogeneration cycles with flat and hyperbolic collectors in both base and improved modes with a porous material (copper foam with 90 percentage porosity) and Nanofluid with different percent's calculated. In the first step, it is planned to design a cogeneration system based on the required load, and in the next step, it will analyze the energy and exergy of the system in a basic and optimize mode. In optimize mode enhance solar collectors with porous material (full and partially) and Nanofluid in (0.1%, 0.3%, 0.5%).

CYCLE DESCRIPTION

Today, we are experiencing global warming which leads to higher surrounding temperature. Most of electricity generation in Iran is still dominated by fossil fuel as main energy source like coal, oil, and gas [26]. Solar Cogeneration is one of the methods to enhance energy efficiency, reduce energy loss, and reduce energy costs.

At first, in order to the design of the cogeneration system and its analysis, it is necessary to calculate the electrical, heating (heating load is the load required for warm water and space heating) and cooling load required for the case study considered a residential building with an area of 480 m^2 in the warm region of Iran (Zahedan). In Table 1, the average of the required loads is shown for the different months of a year.

According to Table 1, the maximum magnitude of heating, cooling and electrical loads are used to calculate the cogeneration system (average electrical, heating and cooling load calculated with CARRIER software). The maximum electric load is 76 kW in August, the maximum amount of heating load is 52 kW in February and the maximum cooling load is 108 kW in August. Since the calculated loads are average, all loads increased up to 10% for the confidence coefficient. With the obtained values, the solar collector area and other cogeneration system components are calculated. The cogeneration cycle is capable to produce 85 kW electric power, 120 kW cooling capacity and 100 kW

Table 1. The average amount of electric charges, heating load and cooling load used in the different months of the year in the city of Zahedan for a residential building with 480 m^2

Month	Electrical load (kW)	Heating load (kW)	Cooling load (kW)
April	53	21	16
May	58	18	38
June	69	13	56
July	72	8	99
August	76	7	108
September	68	9	76
October	60	16	41
November	48	28	25
December	52	36	0
January	54	43	0
February	60	52	0
March	57	39	9

heating power. (The required heat is 55 kW, but in terms of designing the desired cycle, the minimum power production capacity is 100 kW). The SCCHP cycle with a flat plate collector is shown in Figure 1. And parabolic solar collector is shown in figure 2.

System Analysis Equations:

To simplify the analysis, the following assumptions are considered:

1. The system operates under steady-state conditions.
2. The pressure drop in heat exchangers, separators, storage tanks and pipes are ignored.
3. Sediment formation in tubes and collectors is neglected.
4. All components are assumed adiabatic.

Schematic shape of the cogeneration cycle is shown in figure 3.

Based on first law of thermodynamic, energy analysis is based on the following steps.

First of all, estimated solar radiation energy on collector has been calculated

$$\dot{Q}_s = A \times I_b \times \alpha \tag{1}$$

Figure 1. Cogeneration cycle with flat plate collector.

Figure 2. Parabolic solar collectors.

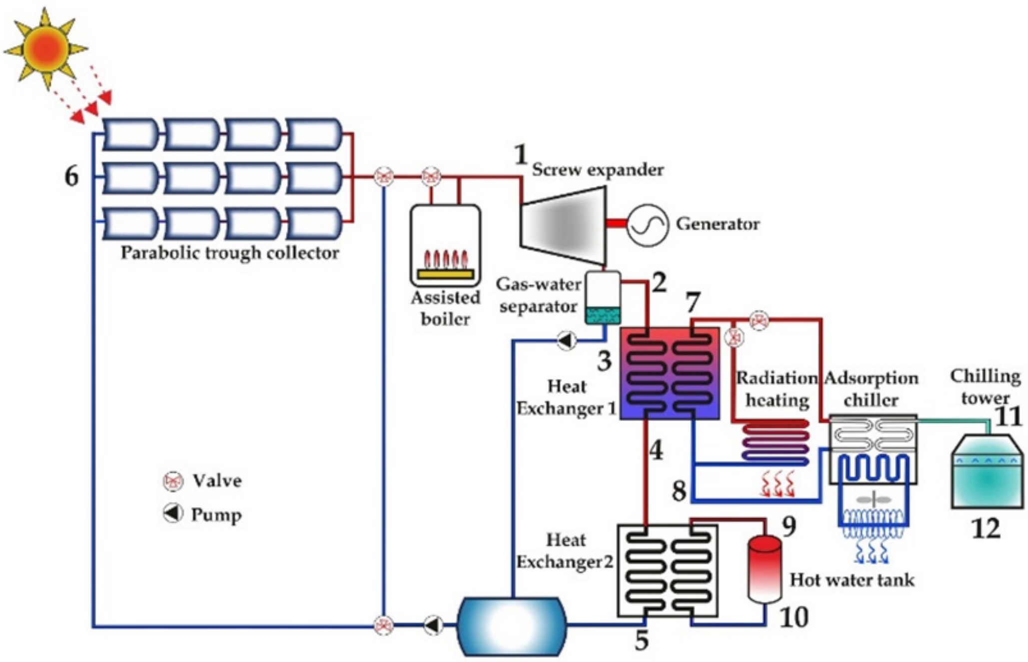

Figure 3. Schematic shape of the cogeneration cycle.

Table 2. Temperature and humidity of different points of system

state	Temperature summer (°c)	Temperature winter (°c)	humidity (%)	Enthalpy-summer (Kj/Kg)	Enthalpy-winter (Kj/kg)	Entropy-summer (Kj/kg)	Entropy-winter (Kj/kg)
1	110	110	0.1	946.7	946.7	2.58	2.58
2	92	92	0.23	913	913	2.63	2.63
3.5.6	85	85	–	367.9	367.9	1.17	1.17
4	90	90	0.04	526	526	1.62	1.62
7	88.8	45	–	372	188.4	1.18	0.64
8	82.1	83.3	–	343.7	348.6	1.10	1.11
9	–	10	–	42	42	0.15	0.15
10	–	78	–	326.5	326.5	1.05	1.05

α is the heat transfer augmentation coefficient, based on porous materials added to the collectors [26]. The coefficient α for flat and parabolic solar collectors is determined by researchers at the Materials and Energy Research Institute. In these experiments, the heat loss dropped sharply by adding porous materials. Solar collectors with copper adsorbent in a discharge above 4 liters per minute had a loss of 67 percent and with nickel adsorbent at a discharge of 4 liters up to 58 percent of the heat loss [26]. In absorption mode, using the porous medium, the heat recovery coefficient is greatly improved. In this case, the average yield increased from 28.45% to 101.6%, depending on the porous medium and flow rate of the fluid flow. The coefficient α is increased by the porosity percentage, the type of porous material (in this case, copper with a porosity percentage of 90) and the flow of fluid flow to the collector equation.

Collector efficiency is going to be calculated by the following equation [27].

$$\eta_c = 0.7 - 0.41\frac{\left(T_1+T_6\right)/2 - T_a}{I_b} \quad (2)$$

Total energy received by the collector is given by [27]:

$$\dot{Q}_c = AI_b\eta_c \quad (3)$$

Also, Auxiliary boiler heat load is [2]:

$$\dot{Q}_b = [(h_1 - h_6)\dot{m}_{st} - AI_b\,\eta_c]\times\alpha \quad (4)$$

Energy consumed from vapor to expander is calculated by [2]:

$$\dot{Q}_{exp} = \dot{m}_{st}\eta_{exp}[h_1 - (h_2'(1-x_{2s}) + h_2''x_{2s})] \quad (5)$$

The power output from by the screw expander [27]:

$$\dot{w}_{exp} = \eta_{exp}\dot{Q}_{exp} \quad (6)$$

The efficiency of the expander is 75% in this case [11].

In this step, cooling and heating loads were calculated and then the required heating load to have sanitary hot water will be calculated as follows:

First step: Calculating the cooling load with eq. (7) [27]

$$\dot{Q}_{cool} = -5.45358 + 0.17373T_7 \quad (7)$$

Second step: calculating heating loads [2]:

$$\dot{Q}_{Heat} = \eta_{HE}(T_2 - T_8)\dot{m}_{heat}C_{p.W} \quad (8)$$

Then calculating required loud for sanitary hot water will be [2]:

$$\dot{Q}_{hotwater} = \eta_{HE}(T_4 - T_{10})\dot{m}_{hotwater}C_{pW} \quad (9)$$

According to the above mentioned equations, efficiency is [2]:

$$\eta_e = \begin{cases} \dfrac{\dot{W}_E + \dot{Q}_{cool}}{\dot{Q}_S + \dot{Q}_G} & summer \\ \dfrac{\dot{W}_E + \dot{Q}_{heat} + \dot{Q}_{hotwater}}{\dot{Q}_S + \dot{Q}_G} & winter \end{cases} \quad (10)$$

In the third step, calculated exergy analysis is:

First, the received exergy collector from the sun is calculated [2].

$$\dot{E}x_s = \left[1 - \frac{4}{3}\frac{Ta}{Ts}\left(1 - 0.28\ln f\right)\right]\dot{Q}_S \qquad f = 1.3\times10^{-5} \quad (11)$$

In the eq. (11), f is the constant of air dilution

Received exergy from the collector is [2]:

$$\dot{E}x_c = (h_1 - h_6)\dot{m}_{St} - (Ta + 273.15)(S_1 - S_6)\dot{m}_{St} \quad (12)$$

In the case of using natural gas in an auxiliary heater, the gas exergy is calculated from the eq. (13) [13]:

$$\dot{E}x_G = 0.95\dot{Q}_g \quad (13)$$

Delivering exergy from vapor to expander is calculated with eq. (14) [27]:

$$\dot{E}x_{exp} = (h_1 - h_2)\dot{m}_{St} - (Ta + 273.15)(S_1 - S_2)\dot{m}_{St} \quad (14)$$

In fourth step, the exergy in cooling and heating is calculated by the following equation:

Cooling exergy in summer is calculated [27]:

$$\dot{E}x_{cool} = \dot{Q}_{cool}\left(\frac{T_a + 273.15}{T_{cool} + 273.15} - 1\right) \quad (15)$$

Heating exergy in winter is calculated [27]:

$$\dot{E}_{x\,heat} = \dot{Q}_{heat}\left(1 - \frac{T_a + 273.15}{T_{heat} + 273.15}\right) \quad (16)$$

In the last step based on thermodynamic second low, exergy efficiency has been calculated from the following equation and the above mentioned calculated loads [2].

$$\eta_{ex} = \begin{cases} \dfrac{\dot{W}_E + \dot{E}x_{cool}}{\dot{E}x_S + \dot{E}x_G} & summer \\ \dfrac{\dot{W}_E + \dot{E}x_{heat} + \dot{E}x_{hotwater}}{\dot{E}x_S + \dot{E}x_G} & winter \end{cases} \quad (17)$$

POROUS MEDIA

The porous medium that filled the test section is copper foam with a porosity of 90%. The foams are determined in Fig. 4, and also detailed thermophysical parameters and dimensions are and shown in (Table 3).

In solar collector's pipe, copper porous materials are used instead of ceramic porous materials. Copper porous materials are suitable for use at low temperatures and have an easier and faster manufacturing process than ceramic porous materials. At low temperatures, such as solar collectors, due to the high coefficient conductivity of copper, the use of copper metallic foam to increase heat transfer is certainly more efficient. Ceramic porous materials are suitable for high temperature applications such as porous burners, which cannot be used with copper or aluminum porous materials.

Simulation solar collectors pipes in FLOW-3D software show in figure 5. Porous media in solar collector's pipe (flat and parabolic) shaped in FLOW-3D, for simulate flat plate solar collector, Solar radiation enters the upper half of the tubes and for simulation parabolic solar collectors, solar radiation enters all surface of solar collector's pipes. Nano particles (Al_2O_3 and CUO) added to working fluids for simulation heat transfer level. After analyzing solar collectors pipes in FLOW-3D software, for analyzing energy and exergy efficiency software outputs were used as EES software input.

Figure 4. Copper foam with the porosity of 90%.

Table 3. Thermophysical parameters and dimensions of copper foam

Material	Copper
Porosity	0.90
Permeability, K (m^2)	1.37×10^{-11}
Diameter of porous media, dp (mm)	31
Thermal conductivity (W/(m.k))	398

NANOFLUID

In this research, copper and silver nano-fluids (Al_2O_3, CuO) have been added with percentages of 0.1–0.5 % of working fluids. The nanoparticle properties are given in Table 4. Also system constant parameters are presented in table 4, which are available as default in the EES program.

System constant parameters for input in the soft wear is shown in (table 4).

The thermal properties of the nanofluid can be obtained from equations (18–21). The basic fluid properties are indicated by the index (bf) and the properties of the nanoparticle silver with the index (np).

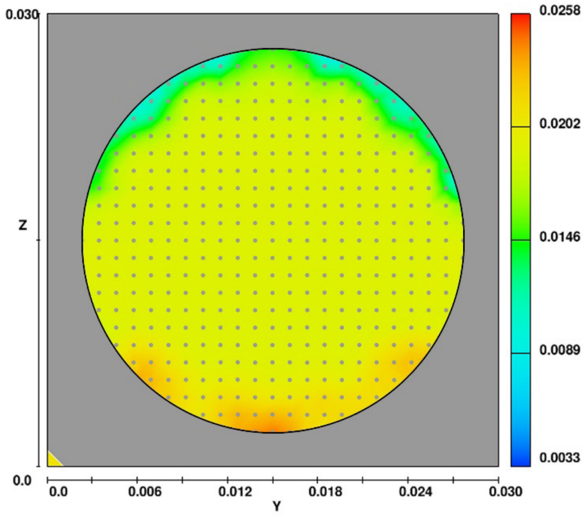

Figure 5. Simulation pipes with full of copper foam and nanoparticles in FLOW-3D software.

The density of the mixture is shown by Eq. (18) [28]:

$$\rho_{nf} = \rho_{bf} \cdot (1 - \varphi) + \rho_{np} \cdot \varphi \quad (18)$$

which ρ is density and ϕ is the nanoparticles volume fraction

The specific heat capacity calculated from Eq. (19) [29]

$$c_{p.nf} = \frac{\rho_{bf \cdot (1-\phi)}}{\rho_{bf}} \cdot c_{p.bf} + \frac{\rho_{np \cdot \phi}}{\rho_{nf}} \cdot c_{p.np} \quad (19)$$

The thermal conductivity of the nanofluid is calculated from eq. (20) [29]:

$$k_{nf} = k_{bf} \cdot \frac{k_{np} + 2 \cdot k_{bf} + 2 \cdot (k_{np} - k_{bf}) \cdot (1+\beta)^3 \cdot \phi}{k_{np} + 2 \cdot k_{bf} - (k_{np} - k_{bf}) \cdot (1+\beta)^3 \cdot \phi} \quad (20)$$

The parameter β is the ratio of the nanolayer thickness to the original particle radius and usually, this parameter is taken equal to 0.1 for calculated thermal conductivity of the nanofluids.

The mixture viscosity is calculated as follows [30]:

$$\mu_{nf} = \mu_{bf} \cdot (1+2.5 \cdot \phi + 6.5 \cdot \phi^2) \quad (21)$$

In all equations, instead of water properties, working fluids with nanofluid is used. All of the above equations and

Table 4. Properties of the nanoparticles [26]

Particle	ρ (kg/m³)	k (W/mk)	cp (kj/kgk)	Density (kg/m³)
Al_2O_3	3970	40	0.765	3950
CuO	6320	77	0.532	6310

Table 5. System constant parameters

Parameters	Values
Average Ambient temperature (T_{am})	25°C
Solar beam irradiation (I_b)	0.8 Kw/m²
Temperature difference in recuperator (ΔT_{rc})	20°C
Electromechanical efficiency of the generator (η_{mg})	98%
Turbine isentropic efficiency (η_{is})	85%
Heat exchanger efficiency (η_{he})	90%
Cover emittance (ε_c)	0.92
Average Wind speed (V_{wind})	1 m/s
Room temperature in summer (T_{rs})	20 °C
room temperature in winter (T_{rw})	24 °C
Sun temperature (T_{sun})	5770 K

parameters are entered in the EES software for calculated energy and exergy of solar collectors and SCCHP cycle. All calculation repeats for both nanofluids and partially and fully porous materials (50%, 70%, 100%) in solar collector's pipe.

RESULTS AND DISCUSSION

In present study, relations were written according to Wang, Dai [12] and the system analysis was performed to ensure the correctness of the code. The energy and exergy charts are plotted based on the main values of the paper and are shown in Figures 6 and 7. The error rate in this simulation is 1.07%.

In the present study in the first step, the collector is modified with porous copper foam material. Eight cases have been considered for the analysis of the production system (Table 6). It should be noted that the embedded of porous media causes an additional pressure drop inside the collector [31, 32]. So in order to heat transfer enhancement in the collector in the range of reasonable pressure drop, using of a partially porous media inside the collector can be a better choice [19, 33, 34]. All eight cases use copper foam with a porosity of 90 percent. In the second step, partially porous media with 50% and 70% fill the solar collector pipe area shown in figure 8.

Results of energy and exergy analysis for eight cases mentioned in Table 6 are depicted in Fig. 9. Maximum efficiency enhancement for the collector has occurred while fully filled porous media is used in which parabolic collector energy and exergy efficiencies are 74.82. % and 31.05% respectively and flat plate collector energy and exergy efficiencies are 47.78. % and 23.36% respectively.

In the previous section, modified collectors have been solely analyzed and energy and exergy efficiencies of them have been presented. In the following, the effect of each collector on the performance of the whole CCHP cycle is

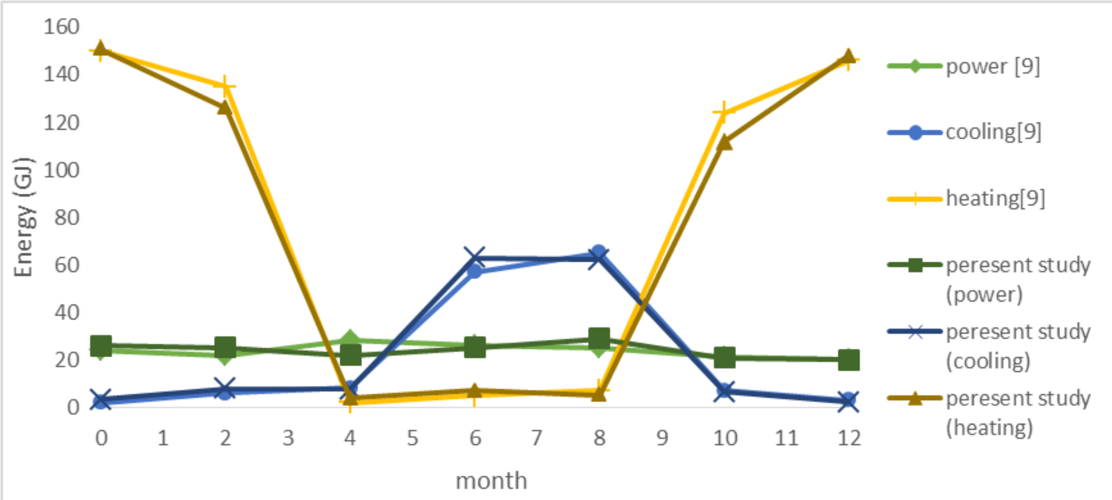

Figure 6. Verification charts of energy analysis results.

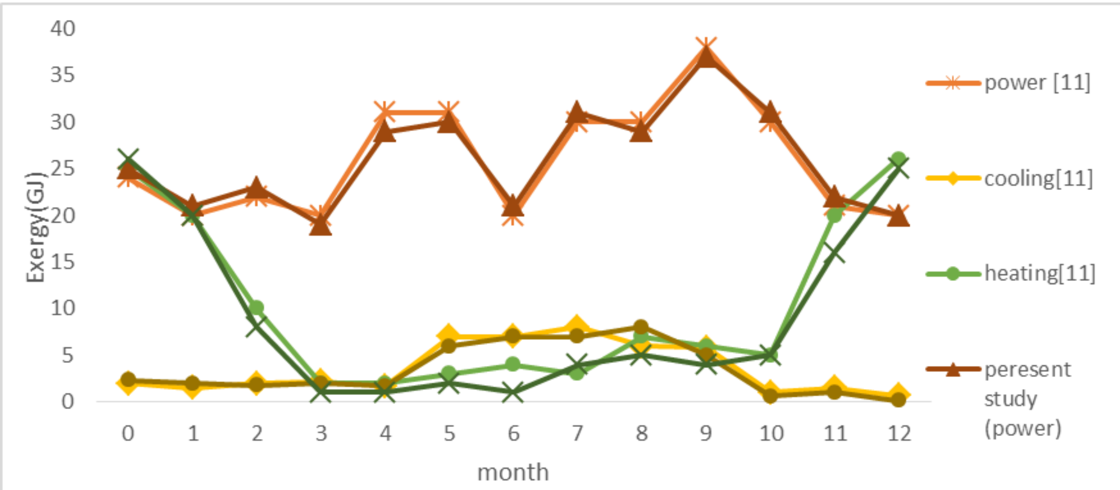

Figure 7. Verification charts of exergy analysis results.

Table 6. Eight cases considered in the present study

1	Simple parabolic collectors
2	Parabolic collectors with 50% partially embedded porous media
3	Parabolic collectors with 70% partially embedded porous media
4	Parabolic collectors with fully filled porous media
5	Simple flat plate collectors
6	Flat plate collectors with 50% partially embedded porous media
7	Flat plate collectors with 70% partially embedded porous media
8	Flat plate collectors with fully filled porous media

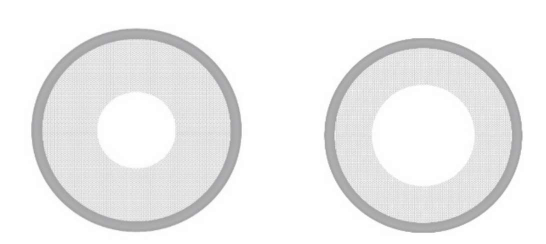

Figure 8. Left pipe with 70% partially embedded porous media, right pipe with 50% partially embedded porous media.

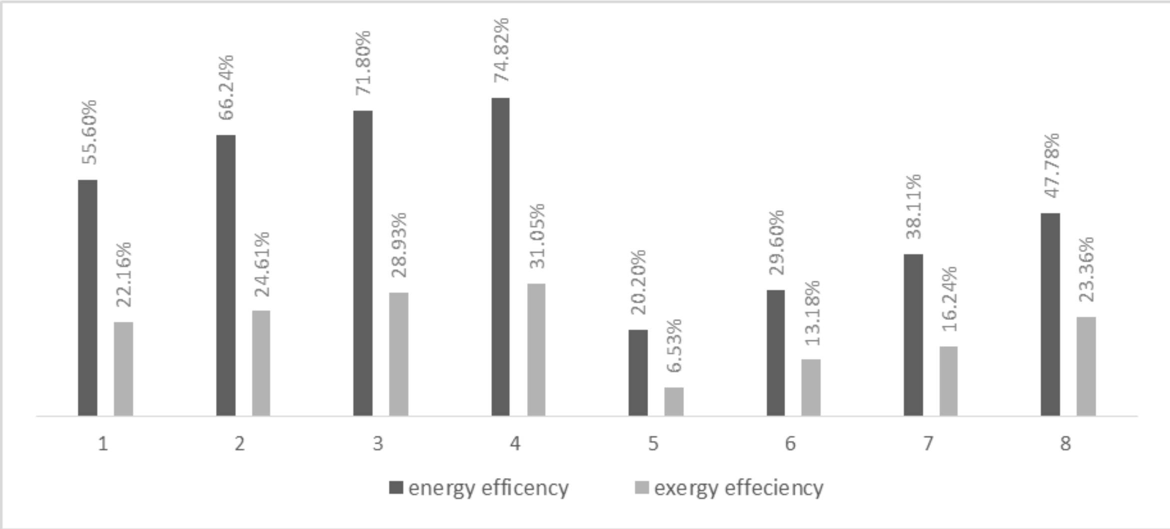

Figure 9. Energy and exergy efficiencies of parabolic and flat plate solar collectors enhanced with porous media.

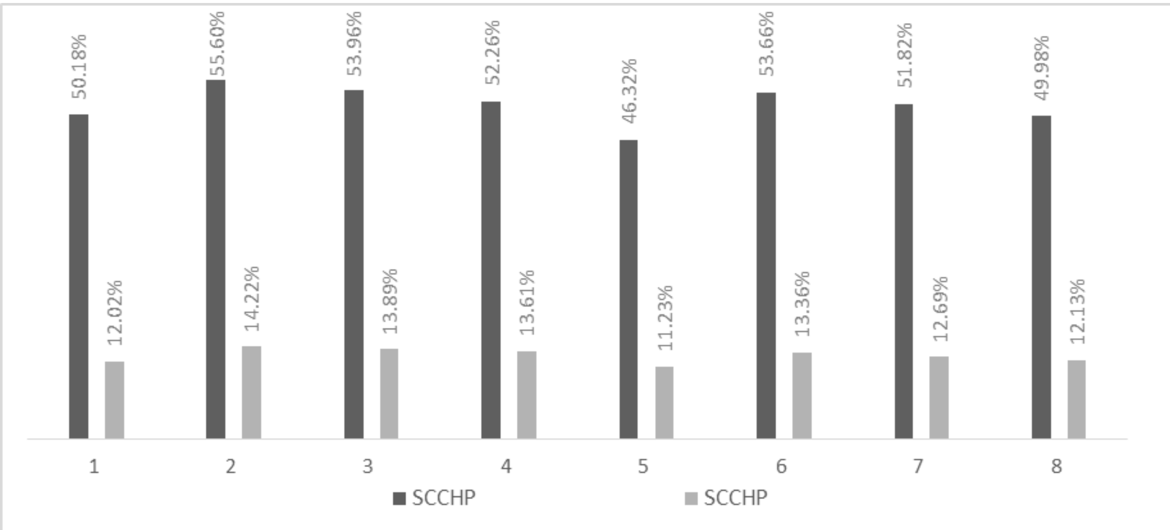

Figure 10. Eight state of SCCHP energy and exergy efficiency with porous material.

described. Figure 10 shows the energy and exergy efficiencies of the whole CCHP cycle at different configurations of solar collectors.

Case 1: Use SCCHP system with a simple parabolic collector. Other modified parabolic collector's results are compared with this base case. According to the calculations, 486 m^2 surface area of parabolic collector is needed to supply the system energy. As shown in Fig. 6, the energy efficiency of the whole cycle in this case is 50.18% and the exergy efficiency of the system is 12.02%.

Case 2: In this case, SCCHP system uses a fully filled porous media parabolic collector. The energy and exergy efficiencies of the whole cycle in this case with surface area 396 m^2 (collector surface area is 18% lower than case 1) are 55.6% and 14.27% respectively.

Case 3: In this case SCCHP system with the parabolic collector that 70 percent of its volume inserted by porous material is investigated. Using partially porous media reduces pressure drop significantly in comparison with case 2. Results of Ref. [35] emphasize that the system pressure drop is mainly less than case 2, while the heat transfer reduction is negligible. The energy efficiency of the system is 53.96% and the exergy efficiency of the cycle is 13.89%.

Case 4: In this state SCCHP system with a parabolic collector that 50 percent of its surface covered by porous

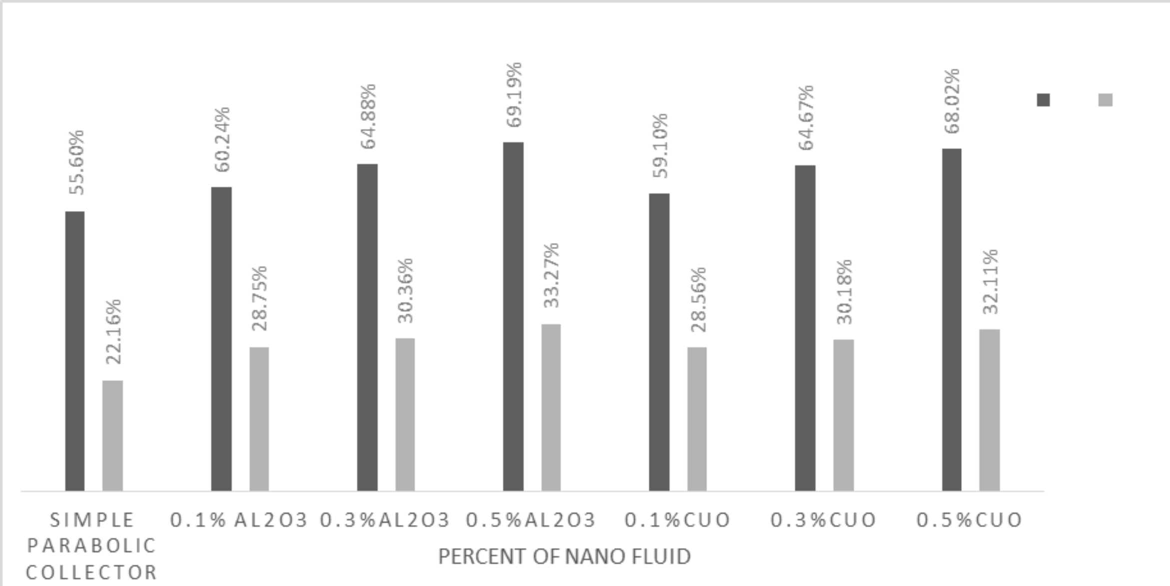

Figure 11. Energy and exergy efficiencies of parabolic solar collectors with Al_2O_3 and CUO Nano fluid.

material is investigated. The energy efficiency of the cycle is 52.26% and the exergy efficiency of the cycle is 13.61%.

Case 5: In this case, a simple flat plate solar collector in SCCHP system is analyzed. Based on the calculation, the required collector surface is 722 m^2 and the need for an auxiliary heater is greater (due to the low output temperature of the flat plate collector relative to the parabolic one). The energy efficiency of the whole system is 46.32% and the exergy efficiency is 11.23%. This case is considered as a base case for other modified flat plate solar collectors.

Case 6: In this case, all the volume of the collector pipes is covered with porous copper materials. Because of the high positive effect of porous media, the required surface area of the collector is reduced 30% in comparison with the base case. The energy and exergy efficiency of the whole cycle is 53.26% and 13.36%, respectively.

Case 7: In this case 70 percent of solar pipes are covered by porous media. The system's energy efficiency is 51.82% and the exergy efficiency is 12.69%.

Case 8: In this state 50 percent of solar pipes are covered by porous materials. The system's energy efficiency is 50.18% and the exergy efficiency is 12.13%.

Based on the results presented in Figure. 7, the highest energy and exergy efficiencies are obtained in case 2 in which fully filled porous media parabolic solar collectors are used. Dou to the high-pressure drop, using partially porous media can be reasonable. One of the drawbacks of the flat plate solar collector is its low efficiency. By adding porous media into a flat plate collector, it is shown a huge enhancement in its efficiency, so that it can be compatible with a parabolic solar collector.

Solar Collectors with Nanofluid

In this section Nanofluid effect on performance of collector and SCCHP systems is investigated. According to previous research about collector modification with Nanofluid, using up to 0.5% of Nano-fluids leads to heat transfer enhancement [19, 33] If more than 0.5% Nanofluid is used, sediment will be inevitable in solar pipes. According to studies conducted on Nanofluid, CuO and Al_2O_3 that increase the absorption of solar energy in a variety of solar collectors is widely used [29].

In the present study, 0.1, 0.3 and 0.5 percent of CuO and Al_2O_3 are added to the simple parabolic and flat plate collectors and energy and exergy efficiencies are calculated based on the simulation result. Energy and exergy efficiencies of a parabolic collector using Nano-particles/water working fluid is illustrated in Fig. 11. Generally, adding of Nanofluid show an increase in energy and exergy efficiencies. Because of higher heat conductivity, enhancement owing to Al_2O_3 is a little greater than CuO [34]. 0.5% of Al_2O_3 increases collector energy and exergy efficiencies up to 69.19% and 33.27% respectively, while these values for 0.5% of CuO are 68.02% and 32.11%, respectively.

In SCCHP systems energy and exergy efficiencies increase using Nanofluid. Results of energy and exergy analysis of the whole cycle are shown in Fig. 12. In parabolic collector with 0.1% Al_2O_3, SCCHP energy efficiency is 51.13% and its exergy efficiency is 12.84%. Using 0.3% Al_2O_3 leads to 52.22% and 13.57% SCCHP energy and exergy efficiencies respectively. While using 0.5% Al_2O_3, SCCHP energy efficiency is 53.07 % and its exergy efficiency is 14.19%. A similar trend is obtained using CuO nanoparticles.

Similar to the parabolic collector, 0.1, 0.3 and 0.5 percent of Al_2O_3 and CuO is added to the working fluid of flat plate collectors and the increase in energy and exergy efficiencies are shown in Figure 13.

Maximum energy efficiency enhancement achieves by adding 0.5% of Al_2O_3. By adding 0.5% Al_2O_3, energy and exergy efficiencies of collector increase to 29.17% and 12.88% respectively while 0.5% CuO Nanofluid increases energy and exergy efficiencies of solar flat plate collector 28.51% and 12.24% respectively.

Obviously, because of the enhancement of efficiency of collector owing to nanoparticle effect, the efficiency of whole SCCHP systems will be enhanced too. Results of energy and exergy of flat plate solar collectors with water/nano working fluid are presented in Figure 14. A case with 0.1% Al_2O_3, SCCHP energy efficiency is 47.52% and its exergy efficiency is 11.84%. With an increase of volume fraction of nanoparticle to 0.3%, SCCHP energy efficiency is 48.17 % and its exergy efficiency is 12.07%. More increase of volume fraction of nanoparticle to 0.5 % leads to higher

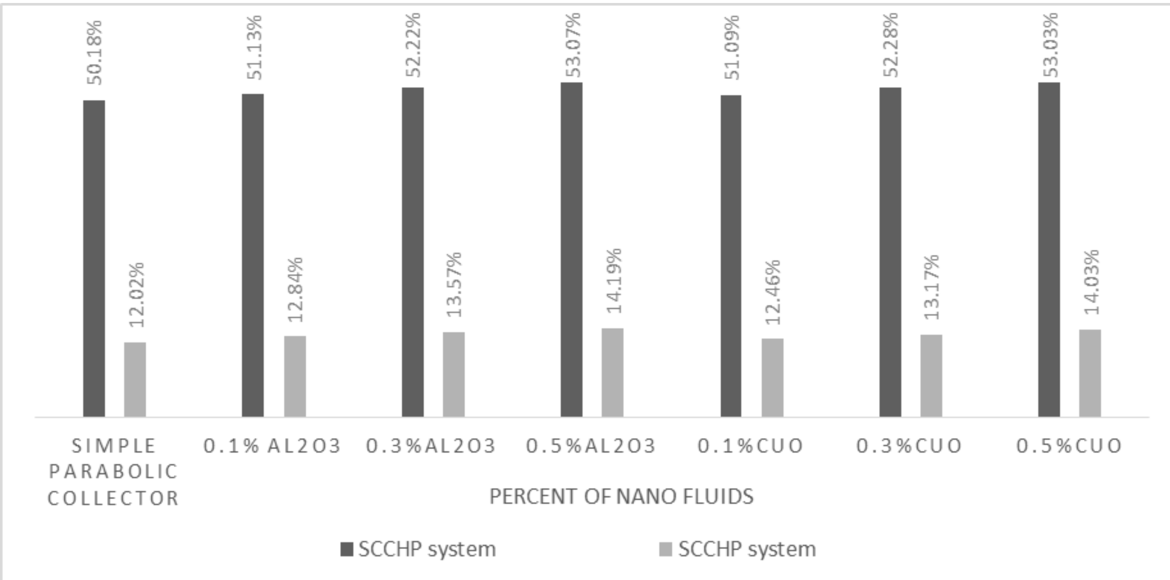

Figure 12. SCCHP energy and exergy efficiency with flat plate solar collector with Al_2O_3 and CuO nanofluid.

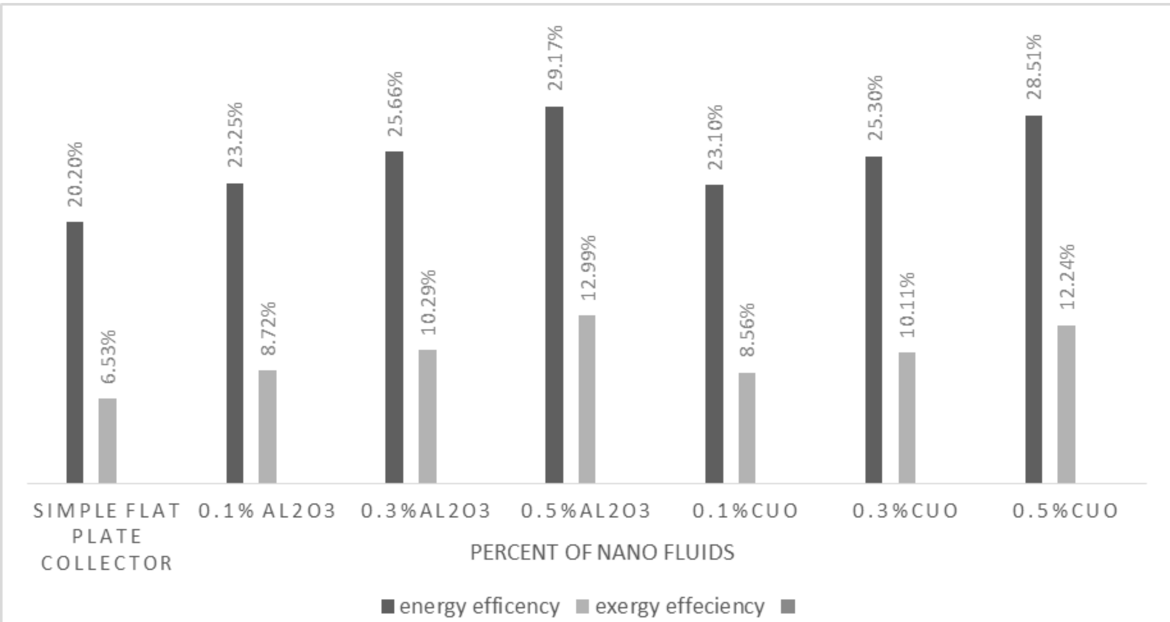

Figure 13. Energy and exergy efficiency of flat plate solar collectors with Al_2O_3 and CuO nanofluid.

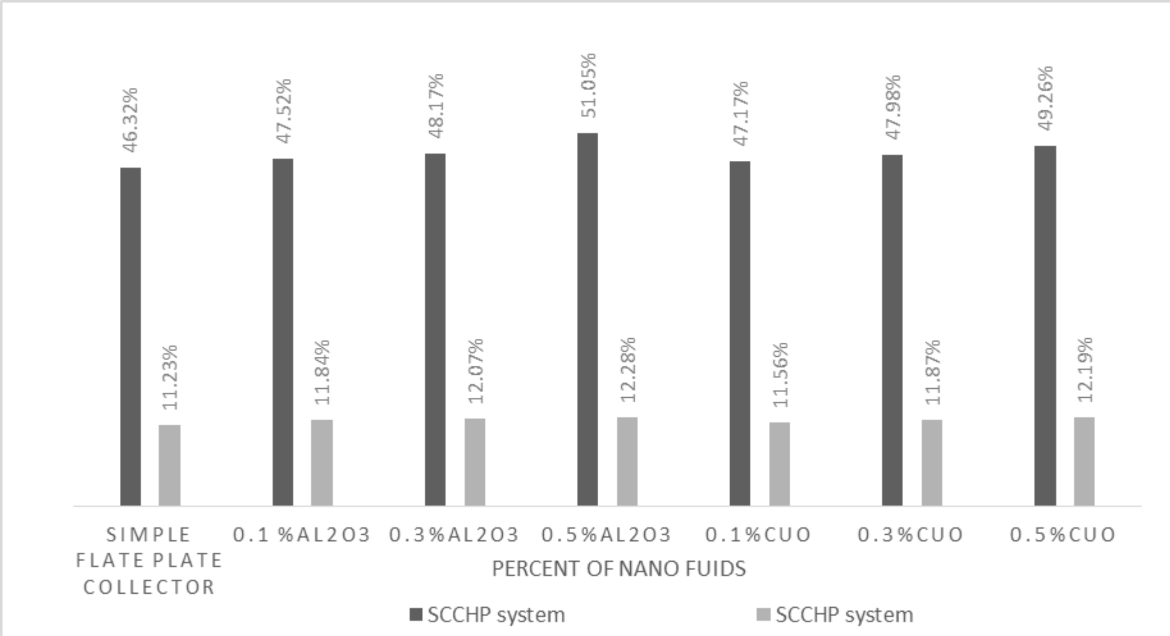

Figure 14. SCCHP energy and exergy efficiency with flat plate solar collector with Al_2O_3 and CuO nanofluid.

energy and exergy efficiencies up to 51.05% and 12.28%, respectively. Although values of energy and exergy efficiencies, when CuO is used, are slightly smaller, the trend of the results is the same.

According to the parabolic and flat plate collectors' efficiency plot, it is observed that using nanofluids and porous media enhance collectors' efficiency further. So that flat plate collectors' efficiency approaches that of parabolic collectors using porous media. Since the production process of flat plate collectors is easier than that of parabolic ones and their production cost is less as well, using porous media in flat plate collectors from a monetary point of view seems to be a good alternative for parabolic collectors.

Since heat transfer using Al_2O_3 is more than that of CuO, this solution enhances the efficiency of flat plate and parabolic collectors as 2%.

The average enhancement of flat plate collectors' efficiency using nanomaterials is 25% while it is 12% for parabolic collectors. Using porous media, the efficiency of flat plate and parabolic collectors enhanced 50% and 30% respectively. The most important outcome of the present study is the higher enhancement of flat plate collectors' efficiency compared to that of parabolic collectors. It is occurred due to higher energy absorption by porous media and consequently a higher increase of collector temperature.

Using porous media and nanofluids solution, the efficiency of flat plate collectors and their output temperatures increase but it is also necessary to make use of auxiliary heaters to increase output temperature and low-pressure vapor generation. Since auxiliary heater compensates collectors' output temperature decrease, the efficiency of both flat plate and parabolic collectors is more than 45% (in flat plate collector, the amount of auxiliary heater work is more).

Porous Material and Nanofluid

In the last section enhanced solar collector with both porous media and Nanofluid is investigated. In the second section that 0.1, 0.3 and 0.5% of Nanofluid added, it is found that 0.5% leads to the highest energy and exergy efficiency enhancement in solar collectors and SCCHP systems. Using concentrations more than 0.5% lead to sediment in solar collector's tubes, decrease of porosity, and tube [34]. In the present study 0.5% CuO and Al_2O_3 concentration added to the collector that embedded by partially and fully filled porous media to achieve maximum energy and exergy efficiencies of SCCHP systems. All steps of the investigation are shown in table 7.

Results show that the highest energy and exergy efficiencies are 76.18% and 35.88% respectively that is achieved in step 9 (parabolic collectors with filled porous media and 0.5% Al_2O_3). In the second step, the maximum energy efficiency is 34.88% and exergy efficiency is 75.64% that occurred in step 12 (Parabolic collectors with 100 percent porous media and 0.5 percent CuO). Energy and exergy results of solar collectors are presented in figure 15.

Energy and exergy of SCCHP system with twelve steps are shown in figure 16.

According to figure 15 maximum energy and exergy efficiencies of SCCHP are achieved in state 9. In this state energy efficiency is 60.12 % and exergy efficiency is 18.84%. Minimum energy and exergy efficiencies of SCCHP has occurred in state 4. Energy efficiency is 12.32% and exergy efficiency is 51.86%. in conclusion solar collectors and SCCHP cycle in twelve state show in table 8. According to the data in Table 8, it can be seen that with solar flat plate collector that filled with porous materials and using Al_2O_3 nanofluids as working fluids can find higher efficiency than the simple parabolic solar collector.

One of the important points of this research is the replacement of simple flat plate solar collector filled with porous materials and using Al_2O_3 and CUO nanofluids instead of simple parabolic collectors, with this replacement the cost of cogeneration cycle is reduced due to the reduction of collector costs.

Table 7. Collectors with 0.5% Nanofluids and porous media

1	Flat plate collectors with 50% partially embedded porous media and 0.5 percent Al_2O_3
2	Flat plate collectors with 70% partially embedded porous media and 0.5 percent Al_2O_3
3	Flat plate collectors with fully filled porous media and 0.5 percent Al_2O_3
4	Flat plate collectors with 50% partially embedded porous media and 0.5 percent CuO
5	Flat plate collectors with 70% partially embedded porous media and 0.5 percent CuO
6	Flat plate collectors with fully filled porous media and 0.5 percent CuO
7	Parabolic collectors with 50% partially embedded porous media and 0.5 percent Al_2O_3
8	Parabolic collectors with 70% partially embedded porous media and 0.5 percent Al_2O_3
9	Parabolic collectors with fully filled porous media and 0.5 percent Al_2O_3
10	Parabolic collectors with 50% partially embedded porous media and 0.5 percent CuO
11	Parabolic collectors with 70% partially embedded porous media and 0.5 percent CuO
12	Parabolic collectors with fully filled porous media and 0.5 percent CuO

CONCLUSION

In the present study, ways for increasing the efficiency of solar collectors in order to enhance the efficiency of SCCHP cycle examined. Three methods were used to increase the collector's efficiency: using porous media, using Nano-fluids and using both porous media and Nano-fluids. The research is aimed at adding both porous materials and nanofluids (up 0.5% to prevent sedimentation in porous media) together. By adding porous materials and nanofluids together, high efficiency in solar collectors can be achieved. The novelty in this research, is the addition of both nanofluids and porous materials can rise the energy and exergy efficiency of flat plate solar collectors up to parabolic solar collectors. In this study, it was observed that by adding 0.5% of Al_2O_3 nanofluid in working fluids, the energy efficiency is 55.28% and by adding 0.5% of CUO nanofluid in working fluids, the efficiency is 54.98%, which is equal to a simple parabolic collector. Due to the lower price of flat plate solar collectors compared to parabolic thermal solar collectors, by using porous materials and copper or silver nanofluids, flat plate solar collectors can be easily used instead of parabolic collectors.

To simulate effect of porous materials and nanofluids, first shaped solar pipes in FLOW-3D software then porous

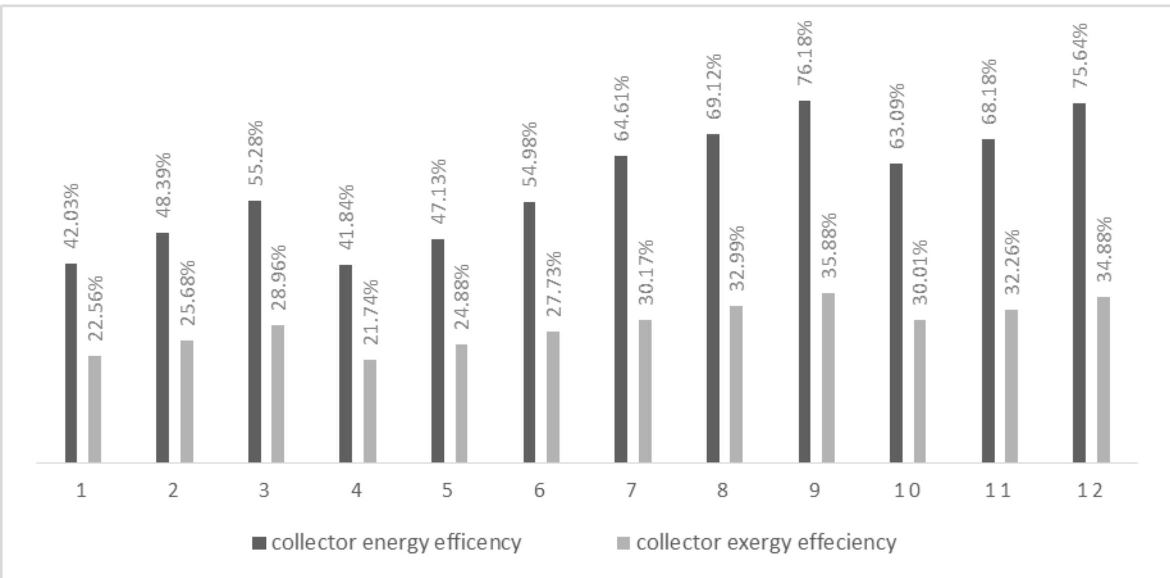

Figure 15. Energy and Exergy Efficiencies of the Solar collector with porous media and nanofluid.

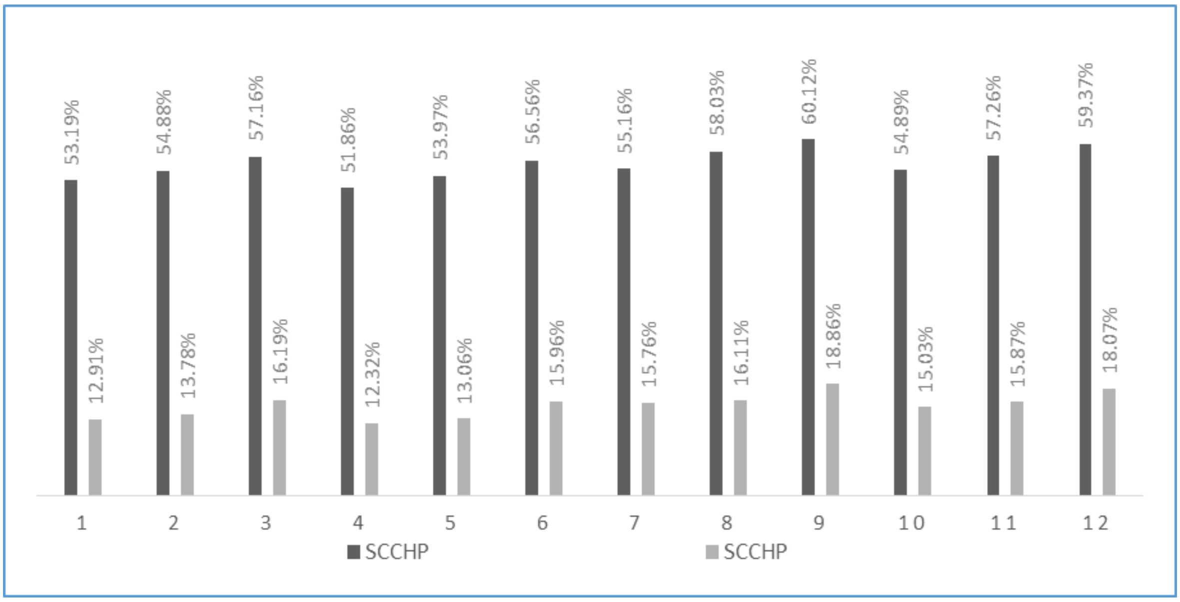

Figure 16. Energy and exergy efficiency of the SCCHP.

Table 8. Solar collectors and SCCHP systems energy and exergy efficiency

State	Collector energy efficiency (%)	Collector exergy efficiency (%)	SCCHP energy efficiency (%)	SCCHP exergy efficiency (%)
Simple flat plate solar collector	20.20	6.53	46.32	11.23
Parabolic solar collector	55.59	22.16	50.18	12.02
Flat plat solar collector with 100% porous media	47.78	23.36	53.66	13.36
parabolic solar collector with 100% porous media	74.82	31.05	55.60	14.22
Flat plat solar collector with 0.5% CUO	28.51	12.24	49.26	12.19
parabolic solar collector with 0.5% CUO	68.02	33.27	53.03	14.03
Flat plat solar collector with 0.5% AL_2O_3	29.17	12.99	51.05	12.28
parabolic solar collector with 0.5% AL_2O_3	69.19	32.11	53.07	14.19
Flat plate solar collector with 100% porous media and 0.5% CUO	54.98	27.73	56.56	13.06
Parabolic solar collector with 100% porous media and 0.5% CUO	75.64	34.88	59.37	18.07
Flat plate solar collector with 100% porous media and 0.5% AL_2O_3	55.28	28.96	57.16	13.06
Parabolic solar collector with 100% porous media and 0.5% AL_2O_3	76.18	35.86	60.12	18.86

media (copper foam with porosity of 90%) and fluid flow with nanoparticles (Al_2O_3 and CUO) added. After analyzing solar collectors pipes in FLOW-3D software, for analyzing energy and exergy efficiency software outputs were used as EES software input.

In the first case this research, flat plate and parabolic solar collectors that covered by 50% and 70% partially and fully embedded porous media in three states (copper foam with a porosity of 90) are investigated. In the second case, flat plate and parabolic collectors in SCCHP cycle were simultaneously covered by different percentages of Al_2O_3 and CuO Nano-fluid. At this stage, three values of 0.1 %, 0.3% and 0.5 % of each Nanofluid were added to the working fluid, and the efficiency of the energy and exergy of the collectors and the SCCHP cycle were determined. In the third case Nanofluid and the porous media were used together in the solar collector, maximum efficiency achieved. In this case, 0.5% of both Nano-fluids were used (to achieve the biggest efficiency enhancement) in different modes of porous materials. In the present study, as expected, the highest efficiency is for the parabolic collector with 100% collector tube covered by porous material (copper foam with a porosity of 90) and 0.5% Al_2O_3. Results of the present study are followed:

1. The average enhancement of collectors' efficiency using porous media is 20%.
2. The average enhancement of collectors' efficiency using nanofluid is 12%.
3. Making use of flat plate collectors that enhanced by porous media and nanofluid, efficiency near that of parabolic collectors can be achieved.
4. Using partially porous media leads to a pressure drop decrease in collectors and also initial cost decrease.
5. Solutions with 0.1 to 0.5% of nanofluids (CuO & Al_2O_3) are used to prevent collectors from sediment occurrence.
6. Collector of solar cogeneration cycles that is enhanced by porous media, nanofluid, or both of them has higher efficiency, and stability of output temperature is more as well. In the above-mentioned collectors, namely flat plate and parabolic collectors, auxiliary heaters are used less, and exergy efficiency is more.
7. Average enhancement of cogeneration cycle efficiency enhanced by porous media, nanofluid, and both of them is 8, 4 and 13% respectively.

NOMENCLATURE

I_b	Solar radiation
a	Heat transfer augmentation coefficient
A	Solar collector area
Bf	Basic fluid
$c_{p.nf}$	Specific heat capacity of the nanofluid
F	Constant of air dilution
k_{nf}	Thermal conductivity of the nanofluid
k_{bf}	Thermal conductivity of the basic fluid
μ_{nf}	Viscosity of the nanofluid
μ_{bf}	Viscosity of the basic fluid
η_c	Collector efficiency
$\dot{Q}_c$	Collector energy receives
$\dot{Q}_b$	Auxiliary boiler heat
$\dot{Q}_{exp}$	Expander energy
$\dot{Q}_g$	Gas energy
$\dot{w}_{exp}$	Screw expander work
$\dot{Q}_{cool}$	Cooling load, in kilo watts
$\dot{Q}_{Heat}$	Heating load, in kilo watts
$\dot{Q}_s$	Solar radiation energy on collector, in Joule
$\dot{Q}_{hotwater}$	Sanitary hot water load
Np	Nanoparticle
η_e	Energy efficiency
η_{HE}	Heat exchanger efficiency
$\dot{E}x_s$	Sun exergy
$\dot{E}x_c$	Collector exergy
$\dot{E}x_G$	Natural gas exergy
$\dot{E}x_{exp}$	Expander exergy
$\dot{E}x_{cool}$	Cooling exergy
$\dot{E}x_{hear}$	Heating exergy
η_{ex}	Exergy efficiency
$\dot{m}_{st}$	Steam mass flow rate
$\dot{m}_{hotwater}$	Hot water mass flow rate
C_{pw}	Specific heat capacity of water
$\dot{w}_{exp}$	Power output from by the screw expander
T_{am}	Average Ambient temperature
ρ_{nf}	Density of the mixture

Greek symbols

ρ	Density
ϕ	Nanoparticles volume fraction
β	Ratio of the nanolayer thickness

Abbreviations

CCHP	Combined Cooling, Heating and Power
EES	Engineering Equation Solver

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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