The Bulletin of Tabbin Institute
for Metallurgical Studies (TIMS)

Vol. 111, (2022)

OPERATING TEMPERATURES EFFECT ON ADSORPTION DESALINATION SYSTEM POWERED BY SOLAR ENERGY.

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ABSTRACT

All of the human actions on earth are influenced by elements such as energy, freshwater, and the environment. Currently, because of the water crisis and the effects of global warming, drinkable water, and environmental impact are the most significant and well-liked study issues. The use of adsorption desalination at various operating temperatures has been studied in the current work using a simulation model. This study also looked at the impact of varying the temperatures of the heat source, evaporator, and condenser. In the current study, a low-grade heat source temperature such as solar energy was used to analyze the performance of a silica gel-water adsorption desalination system using a lumped parameter model. To keep the operating temperature of about 85°C needed to operate the desalination system, the source of heat was already connected to a storage reservoir. Additionally, it has been noted that the adsorption desalination machine produces specific daily water production of about 8 m^3/ton silica gel.

Keywords: Silica gel; Adsorption; Desalination; Renewable energy; Fresh-water.

Nomenclature:

Symbols	
C	Adsorption capacity [kg/kg]
C_O	Maximum adsorption capacity [kg/kg]
C_p	Specific heat [J/kg·K]
D_s	Surface diffusion coefficient [m^2/s]
D_{so}	Pre-exponential coefficient [m^2/s]
E	Characteristic energy [J/kg]
E_a	Activation energy [J/mol]
h_{fg}	Water latent heat [J/kg]
H_{st}	Isosteric heat of adsorption [J/kg]
M	Mass [kg]
$m^{\cdot}$	Mass flow rate [kg/s]
P	Pressure [kPa]
$\bar{R}$	Universal gas constant [J/mol·K]
R_p	Average radius of the particle [m]
T	Temperature [°C]

t	Time [s]
X	Salt concentration [ppm]
Subscripts/superscript	
ads	Adsorption
al	Aluminum
bed	Adsorption bed
ch	Chilled water
$cond$	Condenser
cu	Copper
cw	Cooling water
d	Desalinated water
des	Desorption
eva	Evaporator
hex	Heat exchanger
hw	Heating water
i	Inlet
o	Outlet
s	Salt
sat	Saturation
SG	Silica gel
sw	Seawater
V	Vapor
w	Water
Abbreviation	
Ad_{iso}	Adsorption isotherm
Ad_{kin}	Adsorption kinetics
BET	Brunauer-Emmett-Teller
C_{ads}	Adsorption capacity [kg/kg]
COP	Coefficient of performance [-]
GOR	Gained output ratio [-]
RT	Room temperature [°C]
S_{BET}	BET Surface Area [m^2/g]
SCP	Specific cooling power [W/kg]
$SDWP$	Specific daily water production [m^3/ton per day]
SG	Silica gel
T_{ads}	Adsorption temperature [°C]
t_{cycle}	Cycle time [s]
T_{des}	Desorption temperature [°C]
V_{por}	Pore volume [cm^3/g]
$V_{0.99}$	Total pore volume [cm^3/g]

1. INTRODUCTION

As a consequence of rising water needs, the issue of drinking water and the environment has emerged as one of the most significant and well-liked themes in the field of energy research today. 75% of the surface of the world is covered by water. Freshwater is in low supply in many areas, particularly in Africa and the Middle East. On the other hand, these areas have a lot of saltwater due of their extensive coasts, which has a significant desalination potential [1, 2]. This apparent contradiction results from the fact that only around 2.5% of the water on earth is freshwater, which is found in rivers, lakes, ice, and groundwater [3].

The current desalination processes have drawbacks due of their very large energy consumption. These conventional techniques use between 3.5 and 12 kWh/m3 in total [4-6]. Today's academics face a critical and difficult task: optimizing the use of energy sources and utilizing renewable energy sources [7-10].

The adsorption desalination (AD) system, which is powered by a low-grade heat source, is one such option that can achieve the mentioned objectives. The AD method technology has been developed continuously over the past several decades and is viewed as a potential replacement for conventional desalination systems to address the issues previously highlighted [11-18]. It uses a silica gel and water adsorbent-adsorbate combination as an example. The AD system uses a low-grade heat source to simulate ambient evaporation while condensing water vapor at a high altitude to produce clean water without the need of fossil fuels. Saline water evaporates at low temperatures, usually between 5 and 20 degrees Celsius [3, 19-21]. These plants are thought to use 1.38 kWh/m^3 of specific energy [20, 22, 23].

Specific daily water production (SDWP), specific cooling power (SCP), and coefficient of performance (COP) are three factor that determine how well the AD system performs [24]. The system temperatures have an impact on the AD system's performance [12, 25-27]. The impact of various operating temperatures on the AD system is demonstrated in this study.

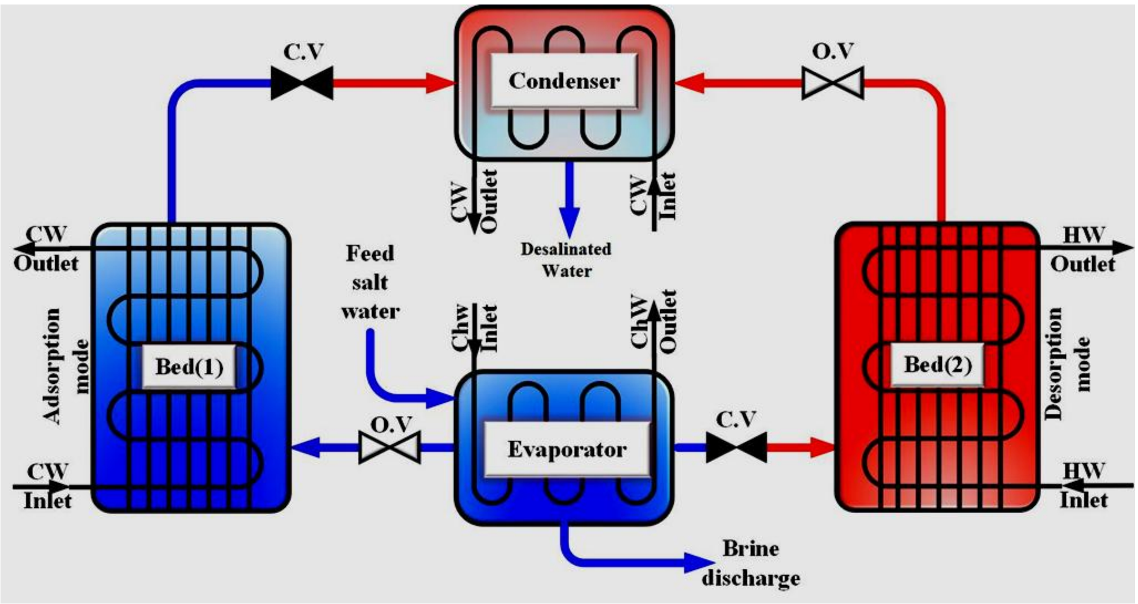

Fig. 1: Layout of the AD system.

2. MATHEMATICAL MODEL

Figure 1 illustrates the three main parts of the AD system: the adsorption beds, the evaporator, and the condenser. Theoretical investigation on the AD cycle for the two-bed mode. It is based on the energy balances between the sorption components, evaporator, and condenser as well as on adsorption isotherms and kinetics. Silica gel is the adsorbent that was employed in this investigation.

The governing equations of the AD system are presented in this section.

2.1. Equilibrium Water Uptake

D-A model estimated for silica gel, adsorption isotherms, (Eq. 1). [12]

$$w = w_\circ exp\left\{-\left(\frac{RT}{E} ln\left(\frac{P_{sat}}{P}\right)\right)^n\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

LDF equation estimated for silica gel, adsorption kinetics. [12, 27]

$$\frac{dC}{dt} = k_s a_v (w_o - w) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where,

$$k_s a_v = F_o \frac{D_s}{{R_p}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$D_s = D_{so} exp\left(-\frac{E_a}{RT}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2.2. Mass Balance Equations

Salt water and condensate water mass balance;

$$\frac{dM_{sw,evap}}{dt} = \dot{m}_{sw,in} - \dot{m}_{p,cond} - \dot{m}_b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Evaporator and salt mass balance;

$$\frac{dM_{sw,evap}}{dt} = \dot{m}_{sw,in} - \dot{m}_b - \left(\frac{d_{Cads}}{dt}\right) M_{sg} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$M_{sw,eva} \frac{dX_{sw,eva}}{dt} = X_{sw,in}\dot{m}_{sw,in} - X_{sw,in}\dot{m}_b - X_D\left(\frac{d_{Cads}}{dt}\right) M_{sg} \quad \ldots\ldots\ldots\ldots (7)$$

2.3. Energy Balance Equations

Adsorption bed energy balance;

$$\left[(Mc_p)_{cu} + (Mc_p)_{al} + (Mc_p)_{sg} + M_{sg} c_{p_v} C\right]^{bed} \frac{dT_{bed}}{dt} = M_{sg} H_{st} \frac{dC_{bed}}{dt} - \dot{m}_w c_{p_w}\left(T_{w,out} - T_{w,in}\right)^{bed} \quad \ldots (8)$$

Heat of adsorption [24];

$$H_{st} = h_{fg} + E\left[ln\left(\frac{C_o}{C}\right)^{\frac{1}{n}}\right] + \frac{ET\alpha}{n}\left[ln\left(\frac{C_o}{C}\right)\right]^{\frac{1-n}{n}} \text{ .... (9)}$$

Condenser energy balance;

$$\left[\left(Mc_p\right)_{cu} + \left(Mc_p\right)_{iron} + \left(Mc_p\right)_w\right]^{cond} \frac{dT_{cond}}{dt} = h_f(T_{cond})\frac{dM_d}{dt} + h_{fg}(T_{cond})\frac{dC_{des}}{dt}M_{sg} + \dot{m}_w c_{p_w}(T_{cond})\left(T_{w,in} - T_{w,out}\right)^{cond}\dot{m}_b \text{ ... (10)}$$

Evaporator energy balance;

$$\left[M_{s,eva}c_{p_s}\left(T_{eva}, X_{s,eva}\right) + M_{cu,eva}c_{p_{cu,eva}}\right]\frac{dT_{eva}}{dt} = h_f\left(T_{eva}, X_{s,eva}\right)\dot{m}_{s,in} - h_{fg}(T_{eva})\frac{dC_{des}}{dt}M_{sg} + \dot{m}_{ch}c_{p_{ch}}\left(T_{ch,in} - T_{ch,out}\right) - h_f\left(T_{eva}, X_{s,eva}\right)\dot{m}_b \text{ .... (11)}$$

The outlet temperature for heat exchangers is expressed by;

$$T_{w,out} = T_{hex} + \left(T_{w,in} - T_{hex}\right)exp\left(\frac{-UA_{hex}}{\left(\dot{m}c_p\right)_w}\right) \text{ .... (12)}$$

The heat of evaporation, desorption, and condensation energy are given by;

$$Q_{eva} = \int_0^{t_{cycle}} \dot{m}_{ch}c_{p_{ch}}\left(T_{ch,in} - T_{ch,out}\right)dt \text{ .... (13)}$$

$$Q_{des} = \int_0^{t_{cycle}} \dot{m}_{hw}c_{p_w}\left(T_{hw,in} - T_{hw,out}\right)dt \text{ .... (14)}$$

$$Q_{cond} = \int_0^{t_{cycle}} \dot{m}_w c_{p_w}\left(T_{cw,in} - T_{cw,out}\right)dt \text{ .... (15)}$$

Cycle performance parameters;

$$SDWP = \int_0^{t_{cycle}} \frac{m_w c_{p_w}\left(T_{cw,out} - T_{cw,in}\right)}{h_{fg}M_{sg}}dt \text{ .... (16)}$$

$$SCP = \int_0^{t_{cycle}} \frac{\dot{m}_{ch}c_{p_{ch}}\left(T_{ch,in} - T_{ch,out}\right)}{M_{sg}}dt \text{ .... (17)}$$

$$COP = \int_0^{t_{cycle}} \frac{\dot{m}_{ch}c_{p_{ch}}\left(T_{ch,in} - T_{ch,out}\right)}{\dot{m}_{hw}c_{p_w}\left(T_{hw,in} - T_{hw,out}\right)}dt \text{ .... (18)}$$

3. RESULTS AND DISCUSSION

The impact of some parameter on SCP, COP and SDWP will be presented as following.

3.1. Effect of Hot Water Temperature

The goal of this effort is to create an AD system that can be powered by a heat source with a low temperature. Figures 2-4 illustrate how hot water intake temperature affects performance in this manner.

According to figure 2, SCP rises from 27 to 317 W/kg of silica gel when the hot water intake temperature rises. Lower than 70–80°C, temperature increase has a significant impact on coefficient of performance (COP). Above this temperature, COP begins to decline, as seen in figure 3. This implies that the majority of the adsorbate is desorbed up to 80°C, after which the amount of desorbed adsorbate rapidly declines. In other words, the larger sensible heat of the desorbed adsorbate vapor in the desorption bed results in increased heat loss.

SDWP is shown in figure 4 at regeneration temperatures between 55 and 95°C. The findings demonstrate that when the hot water intake temperature rises, the AD cycle's water production rate also rises. This is because the regeneration mechanism has been improved to accommodate hotter water temperatures.

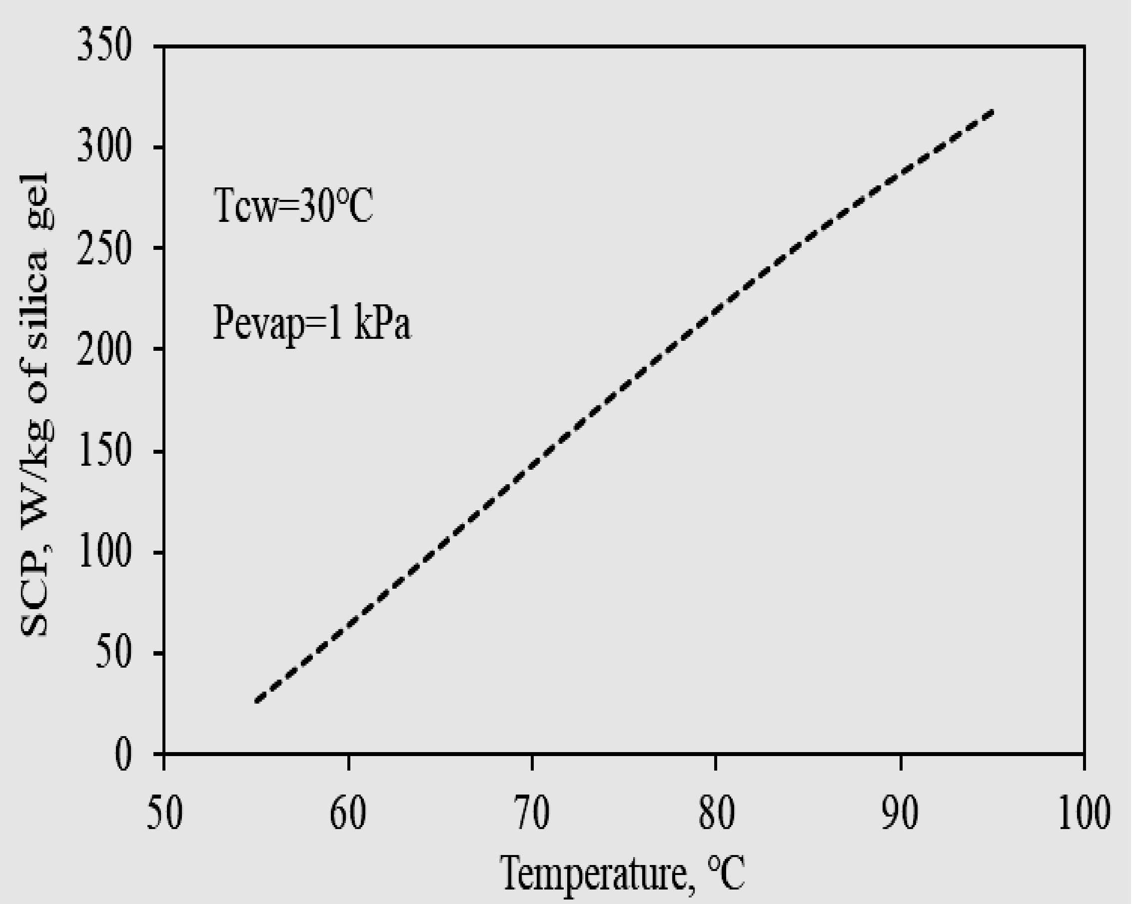

Fig. 2: Variation of SCP at different hot water inlet temperatures.

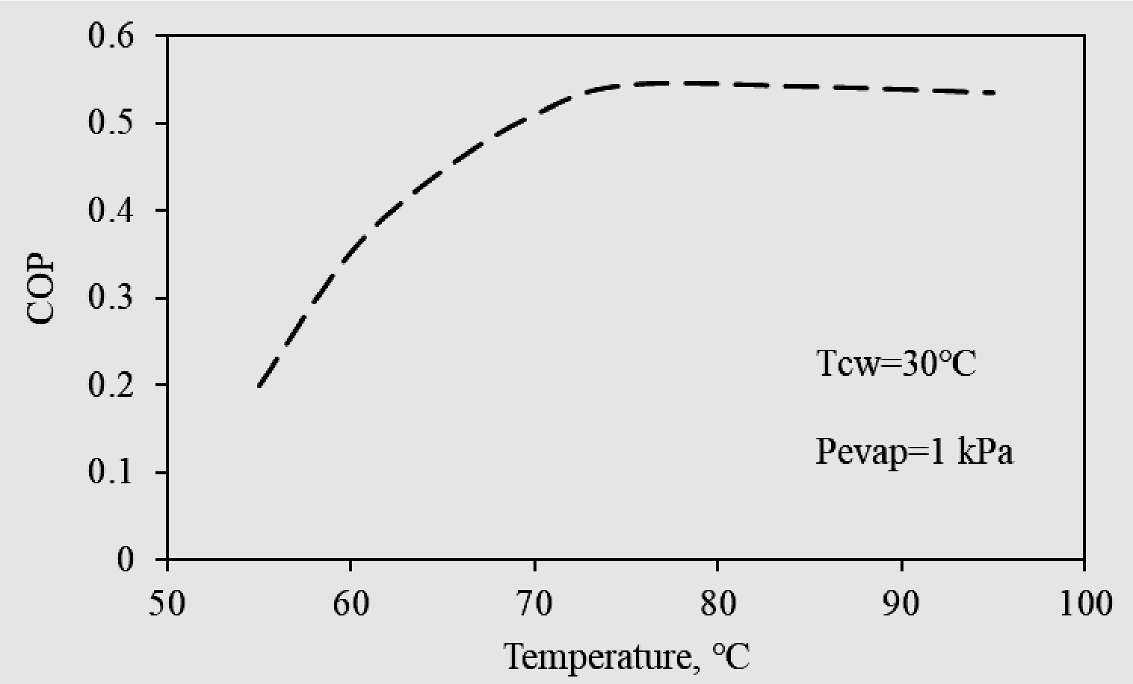

Fig. 3: Variation of COP at different hot water inlet temperatures.

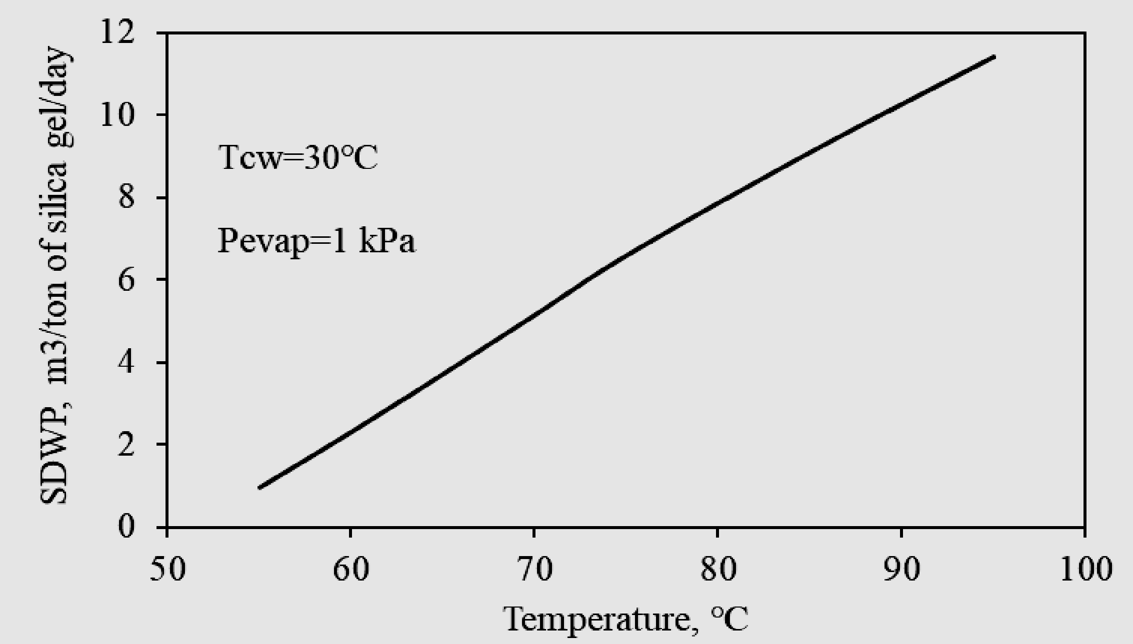

Fig. 4: Variation of SDWP at different hot water inlet temperatures.

3.2. Effect of Cooling Water Temperature

The impact of cooling water intake temperature fluctuation on the adsorbed/condenser is depicted in figures 5-7. Figures 5 and 6 show that as cooling water temperature increases, SCP and COP steadily decline. These are due to an increase in the amount of adsorbate that is adsorbed at the cooler cooling water temperature. At a cooling water temperature of 10°C, the highest values of SCP and COP are 459 W/kg of silica gel and 0.664, respectively.

At a hot water inlet temperature of 85°C, the impact of cooling water intake temperature on the SDWP is also examined. As seen in figure 7, the cycle performs more effectively at lower cooling water temperatures, which results in increased SDWP.

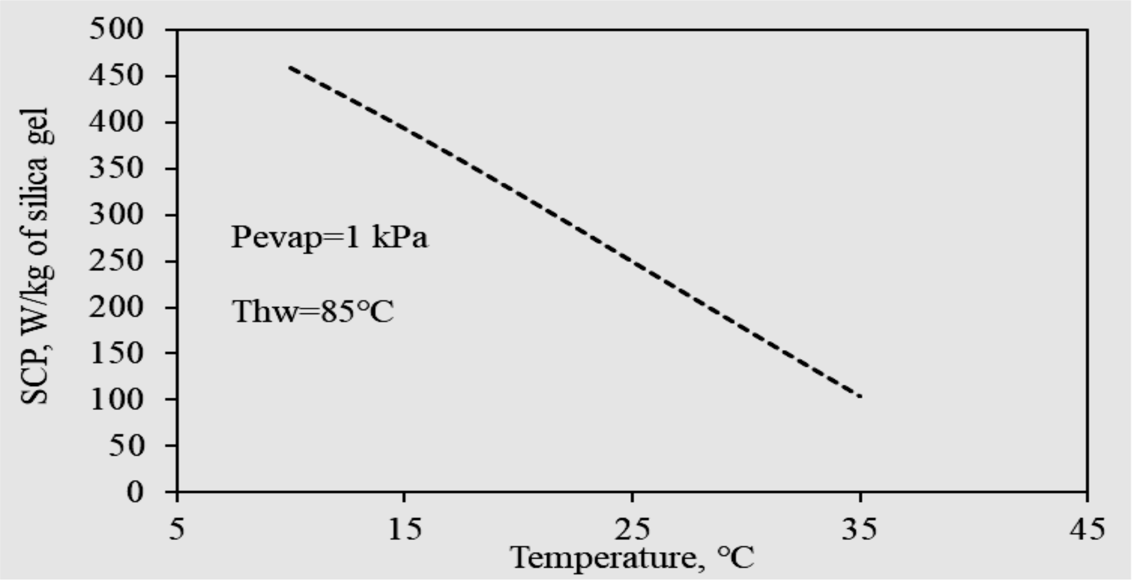

Fig. 5: Variation of SCP at different cooling water inlet temperatures.

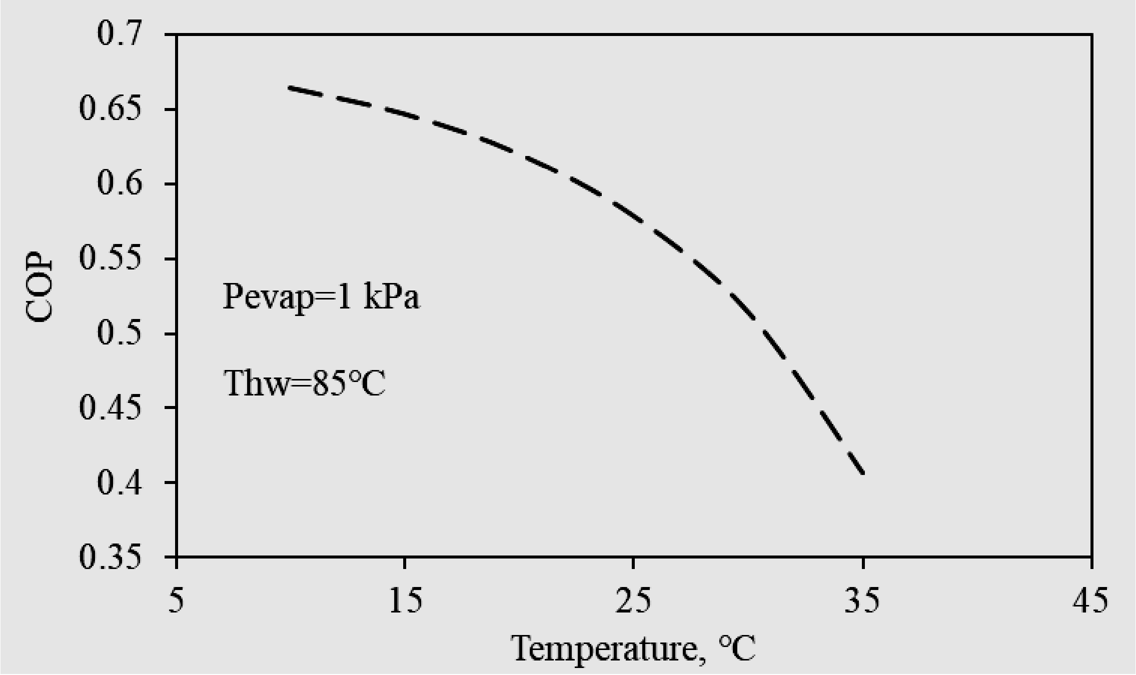

Fig. 6: Variation of COP at different cooling water inlet temperatures.

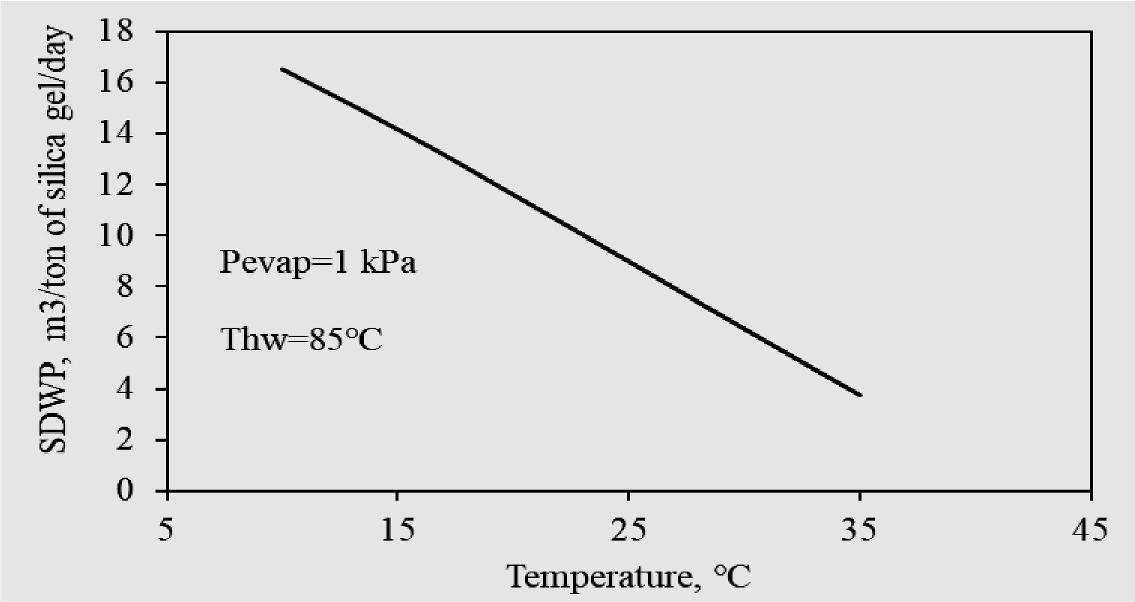

Fig. 7: Variation of SDWP at different cooling water inlet temperatures.

3.3. Effect of Chilled Water Temperature

SCP, COP, and SDWP are used to illustrate how chilled water input temperature affects system performance. According to figures 8, 9, and 10, each SCP, COP, and SDWP decrease as chilled water temperature decreases. Increases in chilled water temperature are obviously associated with an increase in both SCP and COP. However, the researched adsorption desalination-cooling system's performance can be enhanced in relation to the user's desired temperature.

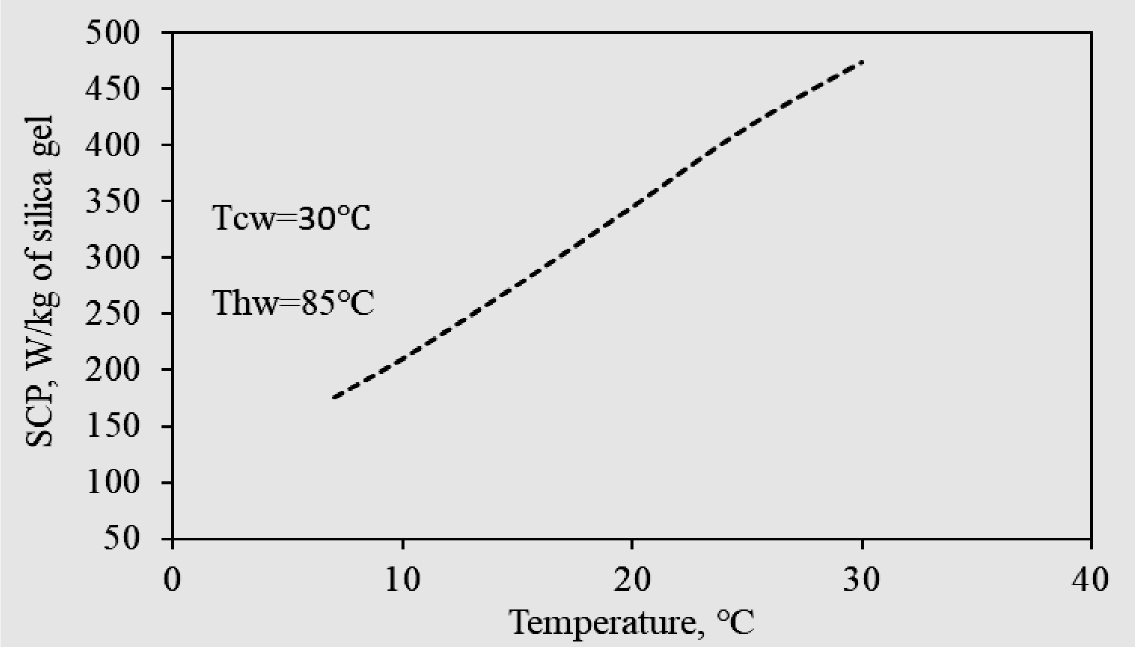

Fig. 8: Variation of SCP at different chilled water inlet temperatures.

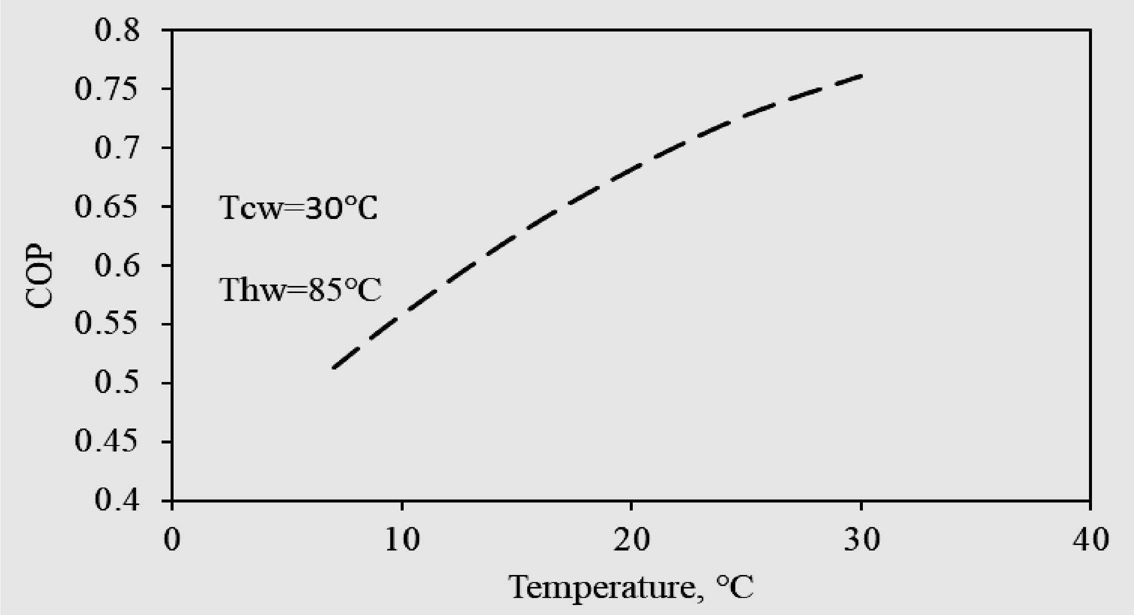

Fig. 9: Variation of COP at different chilled water inlet temperatures.

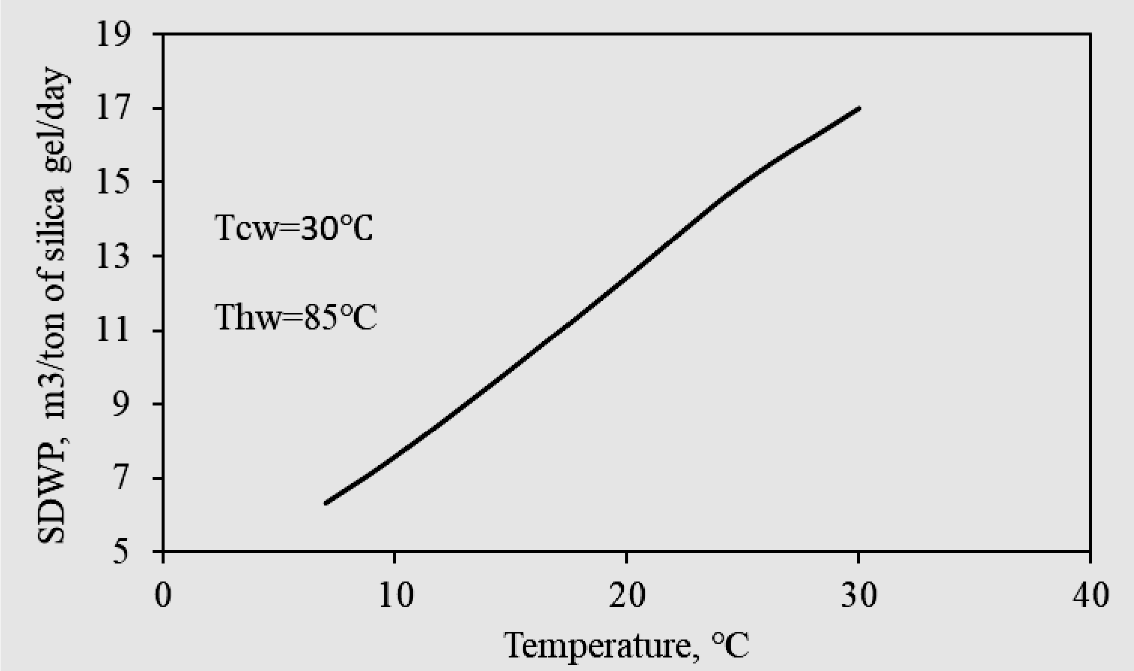

Fig. 10: Variation of SDWP at different chilled water inlet temperatures.

4. CONCLUSION

The adsorption desalination-cooling system can be powered by a low-grade heat source as solar energy, which can be operated efficiently in the Middle East region and Africa weather. From these conclusions, it can be recommended that for future work it is better to increase the performance of the AD system, which can be achieved, by increasing the overall heat transfer coefficient. Future work should also investigate new adsorbent materials as a metal-organic framework (MOF) and composite materials.

Acknowledgments

This work is a part of a research project supported by the Academy of Scientific Research and Technology (ASRT), Egypt through call ASRT Green Fund: Climate Change Adaptation and Nature Conservation. Project no (19409, Eco-friendly water desalination plant for rural areas and coastal regions).

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