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Youssef, Peter George; Dakkama, Hassan; Mahmoud, Saad; Al-Dadah, Raya

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Experimental Investigation of Adsorption Water Desalination/Cooling System Using CPO-27Ni MOF

Peter G. Youssef*, Hassan Dakkama, Saad M. Mahmoud, Raya K. AL-Dadah

4 Abstract — Although many adsorbent materials have been used in adsorption systems, only silica-gel was tested 5 experimentally for desalination applications. This work experimentally and numerically investigates the use of CPO-27(Ni) an 6 advanced Metal Organic Framework-MOF adsorbent material in a 1-bed adsorption system for water desalination and cooling 7 applications. Operating parameters as switching time, half cycle time, evaporator and condenser water inlet temperatures were 8 studied to investigate their effects on cycle water production and cooling. Moreover, a mathematical simulation model is 9 developed, validated and used to predict cycle outputs at other operating conditions. Results showed that as evaporator 10 temperature increases and condenser temperature decreases, cycle outputs increase. Also, it was shown that adsorption 11 desalination cycles can work with condenser pressure lower than evaporator pressure as the cycle is an open loop one (i.e. no 12 refrigerant is flowing back from condenser to evaporator). A water production of 22.8m³/tonne.ads/day was achieved using 40°C evaporator temperature, 5°C condenser temperature and 95°C desorption temperature. Similar water production can be achieved 13 using 30°C condensing temperature but at 120°C desorption temperature. For space cooling applications (T_{evap}<20°C), cycle 14 15 cooling produced was found to be 65Rton/tonne.ads. This work highlights the potential of using advanced MOF materials for 16 water desalination/ cooling applications.

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20 *Keywords*—Experimental, Adsorption, CPO-27(Ni), Desalination, Cooling, Seawater.

21 **1. INTRODUCTION**

Many countries depend on water desalination technologies to meet their potable water needs. Four water 22 desalinating techniques are widely used which are reverse osmosis (RO), multistage flash (MSF), multi-23 effect distillation (MED) and mechanical vapor compression (MVC) [1]. However, these techniques suffer 24 from high power consumption which in turn increases CO_2 emissions and water production costs [2, 3]. 25 Recently adsorption desalination technology was reported to outperform the current conventional 26 technologies in terms of high grade fresh potable water of salinity as low as 10 ppm, lower electric energy 27 consumption of 1.38kWh/m³ and CO₂ emission of 0.6kg/m³ while having lower water production cost of 28 0.2%/m³ [4]. 29

Nomenclature			
Cp	Specific heat at constant pressure (kg. kg ⁻¹ .K ⁻¹)	SDWP	Specific daily water production (m ³ t ⁻¹ day ⁻¹)
h	Enthalpy (kJ.kg ⁻¹)	Т	Temperature (K)
М	Mass (kg)	W	Uptake (kg.kg ⁻¹)
m	Mass flow rate (kg.s ⁻¹)	W^{*}	Equilibrium uptake (kg. kg ⁻¹)
п	Adsorption/Desorption phase, flag (-)	X	Salt concentration (ppm)
Р	Pressure (kPa)	θ	Seawater charging flag (-)
Q_{st}	Isosteric heat of adsorption (kJ/kg)	γ	Brine discharge flag (-)
SCP	Specific cooling power (Rton/t ⁻¹)	τ	No of cycles per day (-)
Subscr	ipts		
а	Adsorbent material	f	Liquid
ads	Adsorption	hw	Heating Water
b	Brine	HX	Heat exchanger
cond	Condenser	in	inlet
cw	Cooling Water	ads	adsorber bed
D	vapor	des	desorber bed
d	Distillate water	out	outlet
des	Desorption	S	Seawater
evap	Evaporator	t	Time

The adsorption water desalination cycle consists of three main components namely adsorption/desorption bed, evaporator and condenser producing desalinated water (from condenser) and 31 32 cooling (from evaporator) [5-9]. The desalination/refrigeration adsorption system depends on the combination of four processes; evaporation due to adsorption and condensation as a result of desorption. 33 Seawater is fed into the evaporator where it is evaporated as a result of the associated adsorption process 34 while extracting heat from the chilled water passing through the evaporator coil producing the cooling 35 effect in this cycle [6, 10]. In the adsorption process, water vapour is adsorbed by the adsorbent material 36 while in the desorption process the water vapour is regenerated by heating and the desorbed water vapour is 37 38 then condensed in the condenser producing fresh water [11, 12].

39

Different adsorbent materials including silica-gel and zeolite have been reported for desalination 40 41 applications using different cycle configurations. Thu et al. [13] experimentally tested an adsorption 42 desalination system operates in two and four bed modes. Heating source temperature and cycle time have been examined during their tests for the two operating modes. It was found that as heat source temperature decreases, longer cycle time is required to obtain the highest water production. In addition, in two bed mode, maximum water production reported was 8.7 m³/tonne of silica-gel/day when 85°C hot source temperature was used while for four bed mode, at the same heating temperature, 10 m³/tonne of silicagel/day was produced.

Ng et al. [8], have used a 215 m² solar collector to obtain the required heating for regeneration of water vapor in a 2 bed silica-gel adsorption system for water desalination and cooling applications. The solar collector produced heat source temperature varying from 65 to 80°C which used to produce 3-5 m³ of desalinated water and cooling in the range of 25-35 Rton/tonne of silica-gel at chilled water temperature of 7 to 10° C.

53 Mitra et al. [14], have introduced a new adsorption cycle for desalination and cooling. This system has 2 stages with 2 beds per stage. Simulations as well as experiments have been carried out at different 54 evaporator pressures and half cycle times to predict desalinated water output, cooling capacity and 55 coefficient of performance (COP). Results showed that maximum produced desalinated water is 1 m³/tonne 56 silica-gel/day while cooling capacity is 7.5 Rton/tonne silica-gel with COP value of 0.25. These results 57 were obtained at evaporator pressure of 1.7 kPa and half cycle time of 1800 sec. The authors attributed 58 these low production capacities, compared to literature, to the quite high ambient temperature, 41°C, which 59 affected the performance of the air cooled condenser. In addition, 2-3 times larger silica gel particle sizes 60 than those reported in literature were used which resulted in slower adsorption/desorption rates. 61

62 Youssef et al. [15], have studied the use of advanced zeolite material, AQSOA-Z02, for adsorption desalination and cooling applications. In their work, a comparison between the AQSOA-ZO2 and silica-gel 63 has been performed when operating in a two bed adsorption cycle for the production of desalinated water 64 65 and cooling. The key parameters of the comparison are SDWP and specific cooling power (SCP) while different heating source temperatures and evaporator water inlet temperatures were applied. It was found 66 that AQSOA-Z02 is less sensitive than silica gel to evaporator water temperature variations. Accordingly, 67 AQSOA-Z02 outperformed silica-gel at lower evaporator water temperatures less than 25°C where at 10°C 68 evaporator water temperature, AOSOA-Z02 cycle can produce 5.8 m³ water per day and 50.1 Rton of 69 cooling while silica-gel cycle generate only SDWP of 2.8 m³ and SCP of 17.2 Rton. On the other hand, at 70 the same heating temperature of 85°C but at 30°C evaporator water temperature silica-gel cycle produces 71 maximum SDWP of 8.4 m³ and 62.4 Rton of cooling. 72

Youssef et al. [16], have investigated the use of AQSOA-Z02 in a novel adsorption system consisting of evaporator, condenser, integrated evaporator-condenser device and 4 adsorber beds. Results showed that by utilizing heat recovery between system components, water production can reach 12.4 m³/tonne adsorbent/day and cooling of 32.4 Rton/tonne adsorbent at evaporator inlet water temperature of 10°C.
 Also, results showed that this system can produce 15.4 m³/tonne adsorbent/day of desalinated water if no
 cooling is required.

Ali et al. [17], have presented a double stage system to produce cooling through stage-1 and desalinated water from condensers of stages 1 and 2. AQSOA-Z02 and silica-gel were used as adsorbents in the two stages, 1 and 2 respectively. A heat recovery was implemented between condensers and evaporators of the system to reduce condenser pressure and increase evaporator pressure which resulted in increased cycle outputs. Results showed that this new configuration produced more water by 26% and 45% more cooling compared to the conventional adsorption desalination and cooling systems.

Elsayed et al. [18], have investigated numerically the potential of using two metal organic framework adsorbent materials (MOF) for different adsorption applications including water desalination and cooling. Isotherms, kinetics and cycle stability were measured for both CPO-27(Ni) and Aluminum fumarate MOF materials where the maximum uptake was 0.47 and 0.53 kg_{water}/kg_{adsorbent} respectively. It was found that at high desorption temperatures (>90°C) and low evaporation temperature (5°C), CPO-27(Ni) outperforms Al-Fumarate. However, Al-Fumarate resulted in better performance at high evaporation temperature of 20°C and/or low bed heating temperature of 70°C.

All reviewed work on water adsorption desalination, showed that silica-*gel* / water is the only working pairs investigated experimentally. This work, experimentally investigates the use of an advanced metal organic frameworks adsorbent material, (*CPO-27Ni*, produced by Johnson Matthey Ltd) in a 1 bed adsorption cycle for production of fresh water and cooling. In addition, a numerical simulation is carried out, validated and used to predict the system performance at other operating conditions.

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98 2. EXPERIMENTAL TEST FACILITY

Figure 1 shows a schematic diagram for a lab scale adsorption test facility developed for the production of fresh water and cooling using CPO-27Ni MOF material as an adsorbent. The main components of this system are: adsorption bed, evaporator and condenser shown pictorially in figure 2.

In such adsorption water desalination system, seawater is supplied to the evaporator where it evaporates during the adsorption half cycle while the adsorber bed is connected to the evaporator. During adsorption time, cooling water is circulated in the adsorption bed to absorb the released heat from the adsorbent material. Then, in the desorption phase, the bed is heated by hot water and water vapor is regenerated. During this desorption process, the adsorber bed is connected to the condenser where the water vapour is condensed producing fresh water. As shown in figure 2, there are other auxiliary components in the system which are heating and cooling water systems for the bed and temperature controllers to supply constant water temperatures for the evaporator and condenser. In addition, there are vacuum pumps to generate the required vacuum pressure in the system. Adsorber bed as shown in figure 3 is a rectangular finned tube heat exchanger with the adsorbent material packed between the fins and surrounded by a metal mesh to keep adsorbent particles in position. The evaporator and condenser are cylindrical vacuum designed chambers with helically shaped cooling coil.

Condenser cooling 115 water in and out 116 117 Condenser 118 119 120 Fresh water out 121 Chiller water out Bed water in 122 Bed water out 123 Chiller water in 124 Adsorber bed Evaporator 125 126 Fig. 1 Schematic diagram for a 1-bed adsorption 127



Fig. 2 Pictorial view for the single-bed adsorption test rig

Unpacked finned tube heat exchanger with fin pitch of 1.016mm

134

135 136



Packed bed and covered with stainless steel mesh

Fig. 3 Pictorial view for the adsorber bed

The experimental test facility is equipped with TJC100-CPSS T-type thermocouples to measure the 137 temperature of the evaporator liquid and gas, adsorbent material in bed and vapor in the bed space. In the 138 139 condenser, RS-pro, k-type thermocouples are used for measuring vapor and condensed water temperatures. 140 Platinum RTD temperature sensors were used to measure bed heating and cooling water inlet and outlet 141 temperatures, evaporator and condenser circulating water inlet and outlet temperatures. The evaporator, condenser and adsorber bed pressures are measured using pressure transducers with an accuracy of 142 143 ±0.01kPa. Flowmeters of type FLC-H14 (0-57 LPM) are used to measure the adsorber bed heating/cooling 144 water flowrate manually with an accuracy of $\pm 1L$ while flowrates of condenser and evaporator water circuits are measured by Parker type flowmeter (2-30 LPM) with an accuracy of $\pm 5\%$. Details of the system 145 component specifications and operating conditions are presented in table I. 146

147	TABLE I System specifications	
149	Property	Value
150	System specifications	
151	Adsorbent mass	0.67 kg
152	Bed metal mass	29.3 kg
153	Evaporator metal mass	15.1 kg
154	Condenser metal mass	15.1 kg
155	Bed heat transfer area	2.55 m ²
156	Evaporator heat transfer area	0.11 m ²
	Condenser heat transfer area	0.16 m^2

157 **3. ADSORBENT MATERIAL CHARACTERISTICS**

158 CPO-27Ni used in this work is an MOF adsorbent manufactured commercially by Johnson Matthey. 159 Figure 4 shows SEM image for this adsorbent material and its physical properties are listed in table II [19-160 21]



Physical Properties of CPO-27Ni		
Property	Value	
Pore mean diameter	0.7 nm	
Surface area	299 m ² /g	
Total Pore volume	217 cm ³ /kg	

174

161

175 176

For prediction of adsorbent material performance, two parameters are required namely adsorption isotherms and kinetics. The maximum amount of adsorbate that can be adsorbed per unit mass of dry material at a certain pressure ratio is called 'adsorption isotherms' while the rate of adsorption or desorption at the operating pressure ratio is called 'adsorption kinetics'. The pressure ratio is defined as the ratio between evaporator to bed pressures during adsorption process or ratio between condenser to bed pressure during desorption process. CPO-27Ni isotherms are modelled using Dubinin-Astakhov (D-A) model (equations 1 & 2) [22] with the constants given in table III [23].

185
$$W^* = W^{\infty} \exp\left[-\left(\frac{A}{E}\right)^n\right]$$
(1)

Where W^* is the predicted equilibrium uptake, W^{∞} is the adsorbed water vapor mass based on the total 186 accessible pore volume [kg_{ref}/kg_{ads}], E is the characteristic energy [J/mol], n is an empirical constant and A, 187 188 is the adsorption potential which is given by:

189

190
$$A = -RT ln\left(\frac{P}{P_o}\right)$$
(2)

Where R is the universal gas constant, T is the temperature of the adsorbent material and P/P_0 is the partial 191 192 pressure ratio.

193

TABLE III			
DUBININ-ASTAKHOV EQUATION CONSTANTS			
Symbol	Value	Unit ^a	
W ∞	0.46826	kg/kg of adsorbent	
Ε	10.0887	kJ/mole	
n	5.6476	(-)	
R	8314	J/mole.K	
^a Units are; kg = kilogram, K = Kelvin.			

194

To determine adsorption kinetics, linear driving force (LDF) model commonly used to predict the rate of 195 adsorption/desorption, (equations 3-4) [24]. Tests using dynamic vapor sorption (DVS) machine have been 196 carried out at university of Birmingham, UK to determine the relation between uptake and time. By fitting 197 the test results, the obtained constants of the LDF model are presented in table IV [23]. 198

199

201
$$\frac{dW}{dt} = k(W^* - W)$$
(3)
202
$$k = k_{\perp} e^{\left(\frac{-Ea}{RT}\right)}$$
(4)

202
$$k = k_o e^{\left(\frac{1}{k}\right)}$$

TABLE IV				
Linear Driving Force, LDF equation constants				
Symbol	Pr ^b <0.2	Pr >0.2	Unit ^a	
k_o	81.5615	0.7779	1/s	
E_{a}	3.2006E4	1.4806E4	J/mol	

^aUnits are; s = second, J = Joule, mol = mole.

^bPr is the pressure ratio between bed and heat exchanger

(4)

For assessment of adsorption desalination/cooling cycle performance, two parameters are calculated which are Specific Daily Water Production (SDWP) and Specific Cooling Power (SCP). SDWP is the amount of water produced per tonne of adsorbent per day while SCP is the amount of produced cooling per unit mass of adsorbent material used. These parameters are calculated using equations 5-8 [6]:

208

$$209 \quad SDWP = \int_0^{t_{cycle}} \frac{Q_{cond} \cdot \tau}{h_{fg} M_a} dt \tag{5}$$

210
$$SCP = \int_0^{t_{cycle}} \frac{Q_{evap} \cdot \tau}{M_a} dt$$
(6)

211 Where:

212
$$Q_{cond} = m_{cond}c_p(T_{cond})(T_{cond,out} - T_{cond,in})$$
(7)

213
$$Q_{evap} = m_{chilled} c_p (T_{evap}) (T_{chilled,in} - T_{chilled,out})$$
(8)

214

215 4. RESULTS AND DISCUSSION

216 As discussed in section 3, adsorbent material performance depends on the partial pressure ratio determined by the adsorber bed and heat exchanger temperatures. For the material to work at low partial pressure ratio 217 during desorption time $(P(T_{cond})/P(T_{Des}))$, this can be achieved either by increasing the heating fluid 218 temperature or decreasing the condenser cooling water temperature. The operating temperature conditions 219 used in this paper were selected to achieve partial pressure ratios ranging from 0.01 to 0.05 corresponding 220 to condensing temperature ranging from 5°C to 30°C at fixed desorption temperature of 95°C while 221 222 adsorber bed cooling water is supplied from the mains at average temperature of 15°C. Flowrates of water circuits in evaporator, condenser and adsorber beds are 4, 5 and 15 L/min respectively. Also, this work 223 224 investigates the effect of other parameters like switching time, cycle time, evaporator water temperature 225 and condenser water temperature on water production and cooling capacity.

226 *4.1 Switching time effect*

Switching time is the period of time when adsorbent bed is not connected neither to the evaporator nor to the condenser. During this time, adsorbent bed is either in precooling or in preheating process to be prepared for adsorption or desorption processes respectively. In this test, five switching times are tested from 5 to 1 min. at constant half cycle time of 14 minutes. Heating and cooling water temperatures are 95°C and 16°C while evaporator and condenser water temperatures are 10°C. Figure 5, shows the adsorber bed temperature through 5 consecutive cycles with switching time decreasing by 1 minute every cycle. It can be seen that as switching time decreases, bed temperature profile becomes more smooth (as indicated by the two circles) leading to reducing the energy demand for heating and cooling the bed. Therefore the

one minute switching time was selected to be the best switching time for all further investigations.

5 min 4 min 3 min 2 min 1 min Bed Temperature (°C) Time (min)





241 4.2 Half cycle time effect

Half cycle time is the time for adsorption or desorption processes during the cycle when the bed is either connected to the evaporator or to the condenser. In this test six half cycle times were investigated ranging from 8 to18 minutes and their results are shown in figures 6 & 7.



Fig. 6 SDWP and amount of collected water per cycle at different half cycle times



248

250

251

Fig. 7 SCP at different half cycle times

Fig. 6 shows that as the half cycle time increases, the amount of water collected per cycle is increasing. 252 253 However, by increasing cycle duration, number of cycles per day will decrease which adversely affects the daily water production. Results showed that half cycle time of 12 minutes can produce the maximum 254 amount of daily water production of 6.8m³/tonne.day. Regarding cooling output, fig. 7 shows that as cycle 255 time increases SCP decreases. This could be attributed to the evaporator temperature profile as it decreases 256 257 at a higher rate at the beginning than at the end of the adsorption time which results in lower average evaporator temperature at shorter cycle times which in turn increases SCP. Although half cycle time of 10 258 259 minutes gives highest SCP of 200 W/kg (57 Rton/tonne.ads), a time of 12 minutes is used for the rest of the 260 experimental work since it results in maximum SDWP which is the main focus of this research.

261

262 4.3 Evaporator and Condenser water temperature effect

Water desalination adsorption cycle is an open loop system which is characterized by seawater feed in the evaporator and desalinated fresh water extraction from the condenser. Accordingly, this cycle is unlike closed loop adsorption refrigeration systems which necessitate condenser pressure to be higher than evaporator pressure to allow flowing of the refrigerant from condenser to evaporator [25]. Different evaporator and condenser water inlet temperatures are investigated with the range of 10-40°C and 5-30°C respectively. As shown in figures 8 and 9, increasing evaporator water temperature increases daily water production and specific cooling power. In contrast, decreasing condenser temperature increases cycle outputs due to the decrease in the operating partial pressure ratio thus allowing desorption process to reach low uptakes. By changing evaporator water inlet temperature from 10 to 40° C, water production increases by 202% from 6.8 to 20.6 m³/tonne adsorbent/day when operating at 10° C condenser. On the other hand, decreasing condenser water inlet temperature from 30 to 5°C, increases cycle water outputs by 135% from 3.2 to 7.5 m³/tonne adsorbent/day at evaporator temperature of 10° C.

Produced chilled water from the adsorption system can be used for cooling applications like space, process or district cooling [6]. Figure 9 shows that this system can produce SCP of 225W/kg for evaporator inlet temperature ranging from 10°C to 20°C suitable for space cooling. Also figure 9 shows that at evaporator inlet temperature ranging from 30 to 40°C, SCP values can reach 750 W/kg which suitable for process cooling.



Fig. 8 SDWP at different Evaporator and Condenser water temperatures

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- 282
- 283
- 284



285

Fig. 9 SCP at different Evaporator and Condenser water temperatures

287

Figure 10 shows temperature profiles of the main system components at two condenser temperatures of 5 and 30° C while evaporator water inlet temperature is constant at 10° C. Two line groups appear in these figures; the first is denoted by (L) and the other is denoted by (H) which refer to temperature profiles in case of low condenser temperature of 5° C and high condenser temperature of 30° C respectively.



293





298 As seen in figure 10-a, at lower condenser water inlet temperature of 5°C with higher water production 299 rates (i.e. higher uptake rate), bed temperature (point 1) cannot reach the low temperature of 22.8°C (point 2) at the end of adsorption process and the high temperature of 84.9°C (point 4) like the case of higher 300 condenser temperature. This is due to the larger amount of heat released and extracted during adsorption 301 and desorption processes respectively by the adsorbent material. In figure 10-b the hatched area represents 302 303 the increase in cooling effect produced in the evaporator due to decreasing the condenser water inlet temperature which resulted in low evaporator temperature of 8°C. In contrast, condenser temperature 304 increases in case of 5°C more than in case of 30°C resulting in area 'B' larger than area 'A', figure 10-c, 305 306 which is because of larger amount of water produced at lower condenser water inlet temperature.

307

308 5. NUMERICAL SIMULATION AND VALIDATION

A Simulink model has been developed to simulate the adsorption water desalination / cooling system shown in fig. 1. This model has been validated using the experimental results and then used to predict the system performance at other operating conditions.

312

313 5.1 Numerical model

314

In order to study the cycle, energy equations are solved for evaporator, condenser, adsorber/desorber bed in addition to mass and salt balance equations for the evaporator [26] as shown in equations 9-13:

- 317
- 318 Evaporator mass balance equation:

319
$$\frac{dM_{s,evap}}{dt} = \theta m_{s,in} - \gamma m_b - n. \frac{dW_{ads}}{dt} M_a$$
(9)

- 320
- 321 Evaporator salt balance equation:

322
$$M_{s,evap} \frac{dX_{s,evap}}{dt} = \theta X_{s,in} m_{s,in}^{\cdot} - \gamma X_{s,evap} m_{brine}^{\cdot} - n X_D \frac{dW_{ads}}{dt} M_a$$
(10)

- 323
- 324 *Evaporator energy balance equation:*

325
$$[M_{s,evap}c_{p,s}(T_{evap}, X_{s,evap}) + M_{HX,Evap}c_{p,HX}] \frac{dT_{evap}}{dt} = \theta \cdot h_f(T_{evap}, X_{s,evap}) m_{s,in} - n \cdot h_{fg}(T_{evap}) \frac{dW_{ads}}{dt} M_a$$

326
$$+ m_{chilled}c_p(T_{evap})(T_{chilled,in} - T_{chilled,out})$$

$$-\gamma h_f \left(T_{evap}, X_{s,evap} \right) m_b \tag{11}$$

328 Adsorption /desorption bed, energy balance equation:

329
$$\left[M_a c_{p,a} + M_{HX} c_{p,HX} + M_{abe} c_{p,abe}\right] \frac{dT_{ads/des}}{dt} = \pm m_{cw/hw}^{\cdot} c_p \left(T''_{cw/hw,in} - T_{cw/hw,out}\right) \pm z \cdot Q_{st} M_a \frac{dW_{ads/des}}{dt}$$
(12)

330

Where, z is a flag equals 0 in heat recovery phase and 1 in adsorption/desorption phase.

332

333 Condenser energy balance equation:

334
$$\left[M_{cond}c_p(T_{cond}) + M_{HX,Cond}c_{p,HX} \right] \frac{dT_{cond}}{dt} = h_f \frac{dM_d}{dt} + h_{fg}(T_{cond}) M_a \left(n. \frac{dW_{des}}{dt} \right)$$

335
$$+ m_{cond}^2 c_p(T_{cond}) \left(T_{cond,in} - T_{cond,out} \right)$$
(13)

336

All energy and mass balance equations in addition to adsorbent characteristics equations (isotherms and kinetics) are solved by Simulink with tolerance value of 1×10^{-6} . In this simulation it was assumed that there is no heat loss from the bed and the temperature of all constituents of each component are kept at the same temperature momentarily.

341

342 5.2 Validation of numerical model

Results of an experimental test at the operating conditions described in table I and at evaporator and condenser water temperatures of 10° C were used for validation. Validation of the developed Simulink model is based on a comparison between experimental and numerical temperatures of bed, evaporator and condenser as shown in fig.11 showing good agreement between the experimental and simulation results with an error within ±10% which is presented on table V. Figure 12 compares the experimental and numerical results of daily water production and specific cooling power with an error of 7.3 and 6.3% respectively.





Fig. 11 Comparison of basic cycle components temperatures for numerical and experimental results of a single-Bed adsorption desalination cycle

355

356

Rad 1	7 50	83
	Maximum (%)	Minimum (%)
DESALINATION CYCLE		
ERROR RANGE FOR THE VALIDATION OF ADSORPTION		

TABLE V

7.59	-8.3
0.44	-6.1
5.92	-0.69
	7.59 0.44 5.92



357

Fig. 12 Comparison of SDWP and SCP for numerical and experimental results for a single-Bed adsorption desalination cycle

358

359 The validated mathematical model was used to investigate the system performance at condensing

temperature of 30°C and higher bed heating temperature of 120°C to achieve the same partial pressure as the case used in the model validation above. Figure 13 compares the predicted SDWP and SCP to those produced experimentally at condensing temperature of 10°C and bed heating temperature of 95°C. It can be seen that they comparable with difference less than 10%. This illustrates that as long as the partial pressure ratio is maintained, the performance of the system will be comparable.

- 365
- 366



367 368

Fig. 13 Comparison of SDWP and SCP for numerical (high desorption and condenser temperatures) and experimental (low desorption and condenser temperatures) results

370

369

371 5.3 Condenser and desorption water temperature effect

SDWP and SCP are shown on figures 14 and 15 respectively at further heating medium inlet temperatures for the range of 110-155°C at different condenser inlet water temperatures ranging from 5 to 30°C. As noticed from experimental results in section 4.3, decreasing condenser water inlet temperature results in more cooling and water production where SDWP and SCP increase by 152% and 95% respectively when condenser water inlet temperature decreases from 30 to 5°C at 110°C desorption temperature. However, increasing desorption temperature enhances cycle outputs as SDWP and SCP are increased by 195% and 96% when desorption temperature increases from 110 to 155°C at the same condenser temperature of 30°C.

379



Fig. 14 SDWP at different desorption and condenser water inlet temperatures



Fig. 15 SCP at different desorption and condenser water inlet temperatures

390 6. CONCLUSIONS

Adsorption water desalination outperforms conventional desalination technologies in terms of energy consumption, CO_2 emissions and water production cost. MOF is a new class of porous materials with

393 exceptionally high water adsorption capabilities. CPO-27Ni is a MOF material with higher water uptake value at low partial pressure ratio compared to silica gel leading to advantages in terms of water 394 395 desalination and cooling production. This work experimentally investigates the use of CPO-27Ni MOF adsorbent material for adsorption desalination/cooling applications. The effect of operating parameters like 396 397 evaporator and condenser water inlet temperatures, half cycle and switching times on the system performance in terms of specific daily water production and specific cooling power were investigated. It 398 was shown that a maximum water production of 22.8 m³/tonne.day was achieved as well as cooling of 399 215.9 Rton/tonne adsorbent at maximum evaporator water inlet temperature of 40°C and condenser water 400 401 inlet temperature of 5°C. This is due to the nature of the isotherm curve of CPO-27Ni and the fact that 402 reducing condenser temperature and increasing evaporator temperature, maximizes the cycle uptake and 403 hence results in more cooling and water outputs. In addition, a numerical model was developed and validated using the experimental results and then used to predict cycle performance at other operating 404 conditions. From this model, it was concluded that as long as the partial pressure ratio is maintained, the 405 same cycle outputs could be obtained using different combinations between condenser and desorption 406 407 temperatures.

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411 **References**

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