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ADSORBENT COATED ADSORPTION CYCLE PERFORMANCE INVESTIGATION

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ABSTRACT

The adsorption cycles are employed in cooling as well as in desalination industries due to its many advantages including waste heat utilization, solar thermal energy application and low maintenance cost. The major bottleneck in conventional adsorption cycles commercialization is its large footprint due to poor heat transfer in adsorbent packed bed heat exchangers. The recent development in coating technologies enabled powder adsorbent to be coated on heat exchanger to improve heat transfer and reduce the footprint of adsorption cycle. We designed an adsorption cycle based on adsorbent coated heat exchanger to investigate the two major parameters such as, the best binder suitable with most commonly silica-gel adsorbent and reliability of adsorbent and binder for commercial applications. The initial experimental investigation showed that silica-gel and hydroxyethyl cellulose (HEC 3% by weight) binder improved the overall heat transfer coefficient to 100-120W/m2-K as compared to 30-40W/m2-K in conventional packed bed AD cycle. In terms of pore surface area, the HEC only block 5-10% of total adsorbent area that showed insignificant impact on performance. We also developed detailed mathematical model to simulate adsorbent coated bed AD cycle performance and to compare with experimental results. Both have good agreement in terms of heat transfer coefficient values. It can be concluded that, the proposed coated bed AD cycle can produce double the amount of desalinated water or cooling effect with same amount of waste heat available.

Key words: adsorbent coating, heat transfer, overall heat transfer coefficient, COP improvement.

1. INTRODUCTION

The adsorbents are applied in almost all industries for various applications. The adsorbent can be easily regenerated using low grade heat sources & solar thermal energy and can be available for next adsorption processes. The most common adsorbents are zeolite, activated carbon, silica gel and metal organic framework. These materials are characterized into Microporous materials: 0.2–2 nm, Mesoporous materials: 2–50 nm and Macroporous materials: 50–1000 nm as per International Union of Pure and Applied Chemistry (IUPAC) [1, 2].

Conventionally, the adsorbents are packed in heat exchangers in the form of cakes. Heating and cooling media is circulated through tubes of heat exchangers for regeneration and adsorption processes. Due to large thermal masses and poor heat transfer, the coefficient of performance (COP) of conventional adsorption cycle, especially chillers, is varies from 0.3-0.7 [3]. Recently, many improvements such as coating of adsorbent granules for higher heat transfer, metal additives mixing, and metallic foam coated with adsorbents were suggested to improve COP of adsorption cycles. These methods can improve the heat transfer to some extent but on the other hand they reduce the adsorption capacity of adsorbent materials [4,5]. These limitations caped the COP of conventional chillers less than 1 since last three decades. Table 1 summarized the laboratory and commercial scale adsorption cycle's COP and it can be noticed that all varies between 0.3-0.7. The performance of adsorption system can be enhanced if the heat transfer can be improved between heat exchanger and adsorbent surfaces.

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Table 1: Summary of COP of adsorption cycles.

Ref #	Study year	COP
[6]	2013	0.65
[7]	2011	0.616
[8]	2010	0.68
[9]	2005	0.16-0.30
Commercial		
Manufacturer	**Capacity (kW)**	**COP**
Sortech	7.5-15	0.56
Invensor	7-10	0.50
Mitsubishi	9.8	0.45

The powder adsorbent coating onto the heat exchanger fins is one of the most feasible and practical solutions to reduce the void spaces and to improve the performance. This can help to increase the heat transfer as compared to packed granular heat exchangers. In this paper, we investigated the performance of silica gel coated heat exchanger and compared it with conventional packed bed heat exchangers adsorption cycle. The detail of experimentation is presented in following sections.

2. EXPERIMENTATION

The commercial powder silica gel pore surface area, pore size and particle size range from 480-580 m^2/g, 60-65 Å, 300-400 mesh respectively. The main challenge in coating silica gel powder on the surface of heat exchanger is to mix with suitable binder by maintaining, (i) pore surface area, (ii) pore structure, (iii) reliability with cyclic operation and (iv) reasonable heat transfer properties. We investigated three different binders with different properties to find out the best binder for mentioned applications. The silica gel power was mixed binder and coated onto the heat exchanger fins as shown in Figure 1 (a,b). The heat exchanger was installed in a chamber connected with small evaporator as shown in Figure 1(c). Important parameters were measured with highly accurate sensors. For example, liquid circulation was measured by Krohne flow meter (accuracy ±1), Yokogawa pressure transducers (accuracy ±0.1 kPa) was installed for pressure tracing and OMEGA thermistors (accuracy ±0.1^{o}C) for temperature tracing. Electrically controlled water baths were used to control regeneration and cooling liquid circulation temperatures. Agilent data logger was used to connect all sensors and data logging.

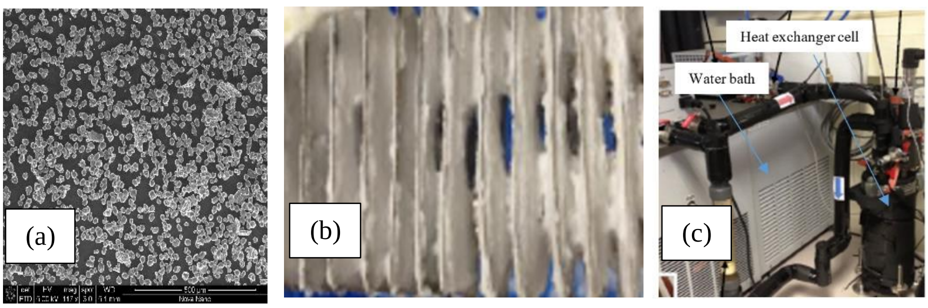

Figure 1: (a) SEM image of silica-gel powder, (b) Silica gel with 4 wt% HEC binder and (c) experimental system [10, all images are reproduced with authors permission].

3. RESULTS AND DISCUSSION

Before coating the adsorbent onto the heat exchanger, they were tested in Autosorb and hydrosorb machines to investigate their properties as shown in Table 2. After testing 3 different binders, it was found that HEC has good binding qualities and it can hold particles up to 140°C but desorption temperature only varies from 55-85°C.

Table 2: Adsorbent properties summary.

Properties	Granular	Powder
Particle size (mm)	0.3	0.08
BET surface area (m^2/g)	600	513
Porous volume (ml/g)	0.42	0.35
Specific heat capacity (J/kg-k)	920	920

The temperature difference (DT) between adsorption bed and cooling media is an important parameter for cycle performance. The lower the value, higher the AD cycle performance as it requires lower pre-heating and pre-cooling phases. It will also effect switching time that impact the overall performance. Figure 2 shows the temperature differences for conventional granular and proposed coated heat exchangers at assorted adsorption temperature.

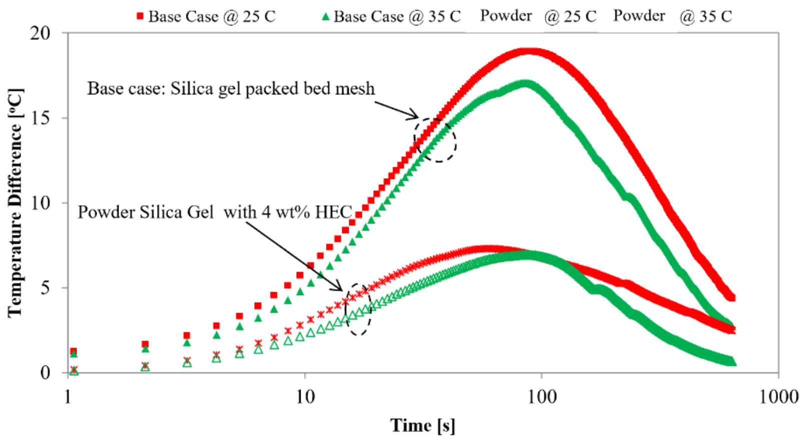

Figure 2: Temperature difference in two cases of AD cycle.

It can be seen clearly that in case of coated heat exchanger, the temperature difference is almost 50% of granular and that reduce energy utilization during pre-cooling and pre-heating accordingly. Also, it will help to reduce cycle as well as switching time.

Figure 3 shows the overall heat transfer coefficient (U) at assorted adsorption temperatures for both granular as well as for proposed adsorbent coated heat exchangers. It can be seen clearly that coated heat exchanger U value is almost 3 times higher than the conventional packed granular heat exchangers. It is mainly due to better contact area of power as compared to larger granular that reduce the void spaces. It shows that for same capacity, coated heat exchanger AD cycle overall footprint will be smaller than conventional systems. The uncertainty of all experimental data was measured as ±1.5%

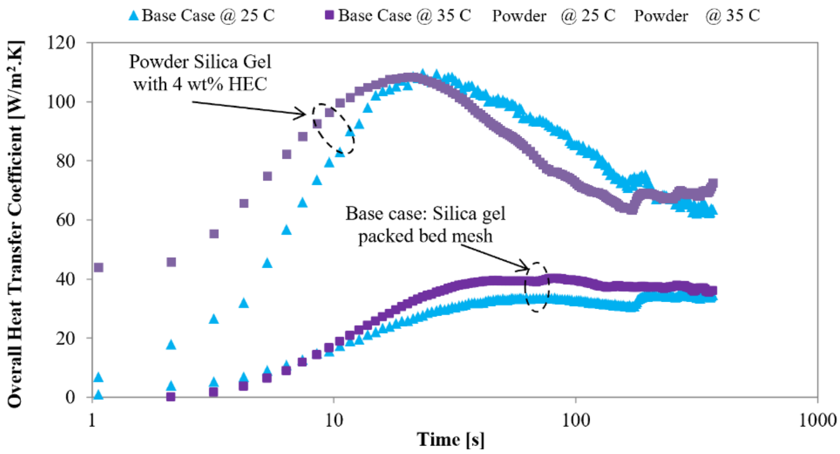

Figure 3: Overall heat transfer coefficient for two cases of AD cycles.

4. SIMULATION VERIFICATION

The theoretical model was developed for both AD cycle cases, and simulation was conducted. The detailed model can be found in the published literature [11-13]. From Figure 4, it can be seen clearly that water production from powder coated AD cycle is 2.3-2.5 times as compared to conventional granular packed bed system. It can also be observed that switching time in case of coated heat exchanger is very short as compared to conventional system.

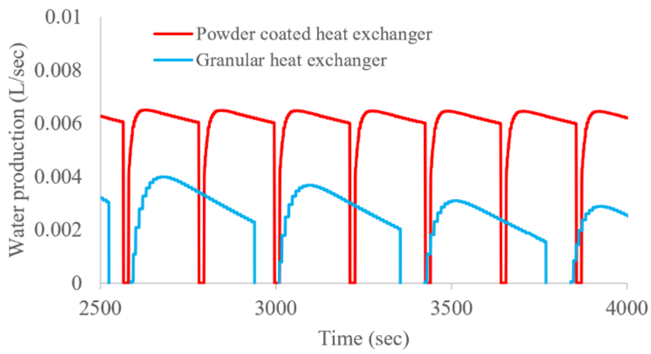

Figure 4: Water production profiles from AD cycle

5. CONCLUSIONS

Experimental study was conducted to investigate the performance of proposed adsorbent coated heat exchanger adsorption cycle. It was successfully demonstrated that coated heat exchanger overall heat transfer coefficient is almost 3 times higher as compared to conventional packed bed system. We also showed that HEC binder is most suitable in terms of adhesion and durability. Simulation was also performed to demonstrate the performance of AD cycle for both cases. It was shown that powder coated heat exchanger performance is almost 2 times higher than conventional system. It clearly shows the advantages of coated heat exchanger AD cycle over conventional packed bed AD cycle.

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