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A Critical Appraisal of Alternative Adsorption Refrigeration System Design Configurations: Enhancing Current Technologies with Innovative Approaches

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ABSTRACT: Adsorption cooling technology (ACT) offers the potential for energy savings and supports environmental sustainability, aligning with current efforts to mitigate the impacts of global warming. However, the current technological advancements to improve its performance and maintain its presence in the market, appear insufficient to compete with the traditional vapour compression cooling systems due to poor energy performance, low COP, high initial cost, low specific energy density, intermittency issue, and reliability issues. The existing ACT operation relies on the use of static adsorbent beds which suffer from poor heat transfer process. Therefore, many research studies focus on addressing design challenges including increasing specific adsorption cooling capacity by using engineered porous materials in combination with environmentally friendly refrigerants. These new advancements can lead to significant improvement in the adoption of adsorption cooling technology beyond the current niche market. The focus of this paper is to appraise critically the various possible innovative mechanical arrangements of the adsorption solid desiccant components for application in heating, cooling and thermal energy storage. The work highlights the design innovation of the solid desiccant bed, particularly in the use of fluidised and moving adsorbent material between the heat source and heat sink. Therefore, the concept of the configurations in this appraisal with their pertinent potentials is intended to overcome the aforementioned identified bottlenecks often encountered by ACT. This appraisal is aimed to provide the required impetus for fast tracking the further development and wider application of adsorption cooling technology.

KEYWORDS: Adsorption, Desorption, Refrigeration, Circulating, Continuous mode, Solid desiccant

I. INTRODUCTION

Affordable and clean energy, nature conservation and people wellbeing are among the main pillars of the united nation's sustainability development goals. The ever-increasing global consumption of fossil fuels-derived primary energy and the ecological impact of refrigerants used in cooling technologies have propelled solid desiccant cooling systems also known as adsorption refrigeration systems (ARS) for extensive research for cooling applications in the fast-growing refrigeration needs of the rural areas of developing countries.

Adsorption refrigeration is one of the greatest encouraging systems for the refrigeration applications due to use of low-grade energy [1]. Adsorption refrigeration technology offers the excellent potential use of low-grade energy sources such as solar or waste heat. The principle of operation of an absorption refrigeration system is based on the phenomenon of physical adsorption between a refrigerant (adsorbate) and a solid desiccant material (adsorbent).

Adsorption refrigeration operates exclusively on heat energy, such as solar or waste heat, without using mechanical energy. This eliminates the need for high grade electrical energy in the compression process of the refrigerant. The functioning of an adsorption refrigeration system is determined by the adsorption and desorption properties of specific adsorbent/adsorbate pairs. The key advantages of adsorption refrigeration systems include low energy consumption, use of low-grade heat sources, zero ozone depletion potential (ODP) and global warming potential (GWP), aligning with current global environmental standards.

II. EMERGENCE OF ADSORPTION REFRIGERATION TECHNOLOGY

Between 1940 and 1945, a calcium chloride/ammonia adsorption refrigeration system (ARS) driven by steam at 100°C was applied for food storage application on a train from London to Liverpool, United Kingdom [2].

Contrastingly from the 1930s, there was a sudden emergence of new technologies such as Freon discovery and the successful development of the totally closed compressor which appreciably improved the efficiency of the conventional vapour compression refrigeration (VCR) technology [3]. Consequently, adsorption refrigeration technology was not able to withstand the CFCs systems which were noted for high efficiency. Hence, its development was confined to specific niche applications. The 1970s energy crisis further offered a renewed interest for adsorption refrigeration technological advancement, as it can operate on low-grade heat sources. It was however the colossal increase in environmental pollution and the shortcomings of the CFCs systems which were identified in 1990 as the major causes of the ozonosphere depletion and global warming problems that buoyed up research efforts for alternative refrigeration systems by academics globally [2]. The first sorption conference held in Paris in the year 1992 favoured this technology to gain more worldwide attention [3]. Since then, this technology with its allied features has always been the area of research interest of both academics and companies globally, with the intention of improving its performance.

A comprehensive plethora of the development trend in solar adsorption refrigeration technology has been previously presented in our precursory work [2]. Presented in Table 1 is an updated summary of the reviewed studies on the development trend in adsorption cooling technology ranging from the basic or intermittent cycles to the advanced cycles (heat recovery cycle, heat and mass recovery cycle, thermal wave cycle, convective thermal wave cycle, cascaded cycle, multi bed and multi stage cycle, fluidised bed technology, constant temperature cycle and hybrid systems). The summary spans through the allied technologies, cycle types, methodology, adsorption working pairs, heat source, applications and the related performance parameters. Even though the results of the reviewed studies summarised in Table 1 might not be directly compared to one another because they were obtained under different operating conditions, they can still be taken as a reference point to what can be expected from such reviewed systems. Going through the transitional development history as well as the study status of scholars globally, it appears the performance of the basic cycle can no longer be significantly improved. In addition, even though higher performances seemed to have been recorded by the advanced cycles, however, they usually require a continuously circulating cooling/heating medium and too many valves to operate uninterruptedly. All these modifications make the systems more complex and expensive.

Table 1 Summary Of Reviewed Works On Development History Of Adsorption Cooling Technology

Cycle type	Methodology	Working pair	Performance parameter	Application	Heat source	Reference
Basic / Intermittent	Exp.	Activated carbon-methanol	M_{ice}: 30–35 kg/day SCOP:0.12	Ice maker	Solar-powered	Pons & Guilleminot [4]
	Sim. and exp.	Silica-gel–Water	SCOP: 0.2	-	Solar-powered	Sakoda & Suzuki [5]
	Exp.	Activated carbon-methanol	M_{ice}: 4 kg/daySCOP:0.1-0.123	Ice maker	Solar-powered	Tan et al. [6]
	Exp.	Activated carbon-methanol	M_{ice}: 4 kg/day SCOP: 0.08-0.12	Refrigerator	Solar-powered	Boubakri et al. [7, 8]
	Exp.	Activated carbon-ammonia	η_c: 36% - 47%	Refrigerator	Solar-powered	Critoph et al. [9]
	Exp.	Activated carbon-methanol	M_{ice}: 4-5 kg/day SCOP: 0.1 to 0.12	Refrigerator	Solar-powered	Sumathy & Zhongfu [10]
	Sim. + exp.	Activated carbon-methanol	M_{ice}: 11.5 kg/m^2 COP: 0.19	Ice maker	Solar-powered	Boubakri et al. [11]
	Exp.	Activated carbon-methanol	M_{ice}: >5.2 kg/day COP: >0.14	Ice maker	Solar-powered	Boubakri [12, 13]
	Sim.	Activated carbon-methanol	M_{ice}: 7–10 kg/day SCOP: 0.13	Ice maker	Solar-powered	Leite & Daguenet [14]
	Exp.	Activated carbon-methanol	M_{ice}: 7–10 kg	Ice maker	Solar-powered	Li et al. [15]
	Exp.	Activated carbon-methanol	COP: 0.09-0.13	Refrigerator	Solar-powered	Buchter et al. [16]
	Sim.	Zeolite–water	COP: 0.17-0.31	Refrigerator	Solar-powered	Li et al. [17]
	Exp.	Activated carbon-methanol	COP: 0.02 η_c : 16.4%	Refrigerator	Solar-powered	Anyanwu & Ezekwe [18]

	Exp.	Activated carbon AC35-methanol	SCOP: 0.05-0.08	Refrigerator	Solar-powered	Lemmini & Errougani [19, 20]
	Sim.	Activated carbon AC35-methanol	SCOP: 0.29–0.38	Refrigerator	Solar-powered	Anyanwu & Ogueke [21, 22]
	Theo.	Silica gel- water; Activated carbon-ethanol; Activated carbon-HFC134a	-	Refrigerator	Waste heat	Saha et al. [23]
	Exp.	Activated carbon-methanol	M_{ice}: 0-6.05 kg/m^2 SCOP: 0.085	Ice maker	Solar-powered	Liete et al. [24]
	Exp. + Sim.	Activated carbon-methanol	COP: 0.078-0.096	Chiller	Solar-powered	Gonzalez et al. [25, 26]
	Sim.	Lithium chloride in silica gel pores-methanol	M_{ice}: 20 kg/m^2 SCOP: 0.33	Ice maker	Solar-powered	Maggio et al. [27]
	Sim.	Activated carbon-methanol	SCOP: 0.211 SCP: 2.326	Refrigerator	Solar-powered	Hassan et al. [28]
	Exp.	Zeolite-water	COP: 0.838 - 1.48	Refrigerator	Solar-powered	Omisanya et al. [29]
	Sim.	Activated carbon-methanol	-	Refrigerator	Solar-powered	Laidi & Hanini [30]
	Sim.	Olive waste-methanol	COP: 0.75	Refrigerator	Solar-powered	Abu-Hamedah et al. [31]
	Exp. + Sim.	Zeolite 4A -water	SCOP: 0.0133.	Refrigerator	Solar-powered	Omisanya et al. [32]
	Exp.	$CaCl_2$ + activated carbon + CaSO4 - NH3	M_{ice}: 0.49–0.63 COP: 0.021 - 0.033	Refrigerator	Solar-powered	Anjorin & Bello [33]
	Exp.	Silica gel-water	COP: 0.07	Refrigerator	Iodine-tungsten lamp	Fatih et al. [34]
	Exp.	Silica gel-water	SCOP: 0.09	Refrigerator	Solar-powered	Bouzeffour et al. [35]
	Theo	Activated carbon-methanol	COP: 0.73	Refrigerator	Solar-powered	Hadj et al. [36]
Advanced / Continuous						
Heat recovery ARC	Exp.	Activated carbon-methanol	M_{ice}: 5–7 kg/day M_{ice}: 5.2 kg/day	Ice maker Refrigerator	Solar-powered; Waste heat	Wang et al. [37, 38]
	Exp.	Activated carbon-ammonia	COP: 0.8	Refrigerator	Solar-powered	Miles et al. [39]
	Exp.	Activated carbon-ammonia	COP: > 1.16	Refrigerator	-	Jones [40, 41]
Heat and mass recovery ARC	Exp. + Theo.	Activated carbon-methanol	COP: > 0.5	Cooler	-	Wang [37]
	Sim.	Silica gel-water	-	Refrigerator	Waste heat	Akahira et al. [42]

	Exp.	Silica gel-water	Cooling capacity: 2–9 kW; COP: 0.2-over 0.5	Water chiller	Electric heater	Liu et al. [43]
	Sim. + Exp.	Silica gel-water	Cooling capacity: 6 kW COP: 0.38	Chiller	-	Wang et al. [44, 45]
	Sim. + Exp.	Activated carbon-methanol	COP: > 0.6	Air-conditioner	Waste heat	Wang [38]
	Sim.	Activated carbon-ammonia	SCP: 104 W/kg; Cooling COP: 0.43; SCOP: 0.18	Refrigerator	Solar-powered	Fadar et al. [46]
	Exp.	Activated carbon-methanol	Cooling effect: 60.75 W-79.87 W Mean cycle COP: 0.196 [47], 0.335 (night)	Refrigerator	Solar-powered	Baiju & Muraleedharan [48]
Thermal wave ARC	Exp.	Activated carbon/ammonia	COP (cooling): 0.76, COP (heating): 1.21	Heat pump	Electric HXF heater	Miles & Shelton [49]
	-	Carbon/ammonia	COP (cooling): 1.0 COP (heating): 1.9	Heat pump	Heater	Jones [50]
	Sim.	Zeolite NaX-water; Activated carbon AXZI-ammonia	SCP: 200 W/kg COP: >1	Heat pump	-	Amar et al. [51]
	Sim.	Zeolite NaX - water	0.87 – 0.21	Heat pump	Heater	Sun et al. [52]
	Sim.	Carbon-ammonia	SCP: 73.0-182.0 W/kg; COP: 0.27- 0.89	Heat pump	Heater	Chahbani et al. [53]
Convective thermal wave ARC	Sim. + Exp.	Carbon-ammonia	COP: 0.90	Cooler	-	Critoph [54, 55]
	Sim.	Zeolite 13X-water	SCP: 125 W/kg COP (cooling): 1.0 COP; COP (heating): 1.9	-	-	Lai [56]
Cascaded Cycle	Exp.	Zeolite-water @ high temperature; Active carbon-methanol @ low temperature	COP: 1.06	Heat pump	Boiler	Douss & Meunier [57]
Multi bed and multi stage Cycle	Exp.	Silica gel–water	COP: 0.36	Chiller	Solar/waste heat	Saha et al. [58]
	Sim.	Silica gel–water	COP: 0.38 T_{cw}: 6 °C	Chiller	Waste heat	Saha et al. [59]
	-	Zeolite-water, LiBr–water	-	Refrigerator	Waste heat	Shu et al. [60]
	Sim. + Exp.	Silica gel–water	CC: up to 2.4 kW COP: up to 0.2	Chiller	Waste heat	Saha et al. [61, 62]

	Sim.	Silica gel–water	CC: up to 7 kW COP: up to 0.55	Chiller	Solar/waste heat	Saha et al. [63]
	Sim.	Active carbon-ammonia	COP (cooling): 0.60; COP (heating): 1.52; CC: 291 W; SCP: 142 W/kg	Refrigerator/heat pump	Heater	Critoph [64]
Fluidised bed technology	Exp.	Activated carbon-R134a	-	Refrigerator	Boiler, blower	Wang et al. [65]
Constant temperature ARC	Sim.	Activated carbon-methanol	M_{ice}: 0.64-0.75 kg/day COP: 0.6	Refrigerator	Solar-powered	Hassan et al. [66]
	Sim.	Activated carbon-methanol	M_{cw}: 2.63kg COP: 0.66	Chiiler	Solar-powered	Hassan & Mohamad [67]
	Sim.	Activated carbon-methanol	COP: 0.61-0.66	Refrigerator	Solar-powered	Hassan et al. [68]
Hybrid systems	Exp.	Zeolite-water	-	Air conditioner + refrigerator	Solar-powered	Tchernev [69]
	Exp.	Activated carbon-methanol	M_{ice}: 10 kg/day; COP: 0.144; heating 60 kg water to about 90 °C	Water heater + Ice-maker	Solar-powered	Wang et al. [70]
	Sim.	Activated carbon-methanol	M_{ice}: 7.2 kg/day; heating 50kg water to about 96 °C; COP: 0.62	Water heater + Ice-maker	Solar-powered	Odesola & Oluleye [71]
	Sim.	Activated carbon-methanol	30 kg hot water of 47.8 °C;COP (cooling): 0.18; COP (heating): 0.34	Water heater + Ice-maker	Solar-powered	Zhang & Wang [72]
	Sim.	Activated carbon-methanol	SCOP: 0.02 η_h: 0.46	Water heater + Refrigerator	Solar-powered	Suleiman et al. [73]
	Sim.	Activated carbon-HFC 134a	COP: 0.07-0.11	Refrigerator	Waste heat	Banker et al. [74]
	Sim. + Exp.	Activated carbon-HFC 134a	COP: 0.04	Refrigerator	Solar/waste heat	Banker et al. [75, 76]
	Sim.	Silica gel-water	SCC: 2-7 Rton/tonne of silica gel; SDWP: 0.3–0.9 m^3/day/ tonne of silica gel; COP: 0.05-0.26	Cooler + desalinator		Mitra et al. [77, 78]

Sim: Simulation; Exp: Experiment; Theo: Theoretical; SCOP: Solar coefficient of performance; M_{ice}: mass of ice; η_c: collector efficiency; SCP: Specific cooling power; ARC: Adsorption refrigeration cycle; T_{cw}: Chilled water temperature; CC: Cooling capacity; M_{cw}: Mass of chilled water, η_h: Heating efficiency; SCC: Specific cooling capacity; SDWP: Specific desalinated water production

Honestly speaking, among the adsorption cycles mentioned above, the heat and mass recovery cycle is one of the easiest cycles to be used in the practical systems. Most of the others are just studied in laboratory [79] or theoretically. They all are often limited by the problem of low COP. The industrial revolutionary inventions trends shown in Table 2 have revealed that some companies have started to successfully develop adsorption chiller/heat pump on commercial scale [80]. However, these systems (often with low COPs) are yet unable to compete or completely replace the conventional vapor compression refrigeration (VCR) systems, due to poor heat and mass transfer characteristics between adsorbent and adsorbate and other aforementioned limitations. As observed in Table 2, silica-gel /water with COP range of 0.4 -0.75 has been the mostly used adsorption pair due to its relatively high COP, high adsorption uptake and less reduction of adsorption uptake capacity for reparative cycle.

Table 2 Companies Revolutionary Inventions

S/N	Company Name	Working Pair	COP	Load	Regeneration Temperature	Evaporator Temperature
1	Weatherite Manufacturing Limited West Midlands (UK)	Silica-gel/Water	0.75	3 MW	50°C-90°C	3°C
2	Invensor Berlin (Germany)	Zeolite/Water	0.61	3 kW-11 kW	45°C-100°C	5°C
3	Solar Tech AG German	Silica-gel/Water	0.56	15 kW	75°C-95°C	N/A
4	Mitsubishi Plastic and Union Industry Co. Ltd. Japan	Zeolite/Water	0.45	10 kW	65°C-75°C	11°C-16°C
5	HIJC USA	Silica-gel/Water	0.45	570 kW	50°C-90°C	3°C-9°C
6	Qianchuan Canada	Silica-gel/Water	0.6	N/A	70°C	14°C
7	Mayekawa Japan	Silica-gel/Water	0.4	105 kW	50°C-80°C	5°C-15°C
8	Bry-Air (Asia) Pvt. Ltd.	Silica-gel/Water	0.48	10 kW	90°C	3°C-20°C

Source: [80]

Therefore, an appraisal of different designs and discuss of the merits and limitations of each alternative configuration for adsorption solid desiccant cooling/heating systems is presented in this work. The discussion centres on assessing each configuration's strengths and weaknesses and identifying the potential of each in effectively addressing those research gaps previously identified. The main design innovation considered in this work relates to the way in which the solid desiccant is circulated hermitically between the heat source and the heat sink. Furthermore, the concept of the configurations evaluated in this work with their pertinent potentials (including continuous cold production, eradication of the issue of unnecessary load on the evaporator, maximum optimization of both adsorption and desorption processes due to the spatial separation of both desorber and adsorber, absence of thermal stress induction in the bed as heat source and heat sink heat exchangers are localised) is intended to overcome some of the aforementioned bottlenecks often encountered by adsorption cooling technology.

III. ALTERNATIVE ADSORPTION REFRIGERATION SYSTEM DESIGN CONFIGURATIONS

The following discuss the configurations of three main alternative designs:

A. *Design arrangement 1: Adsorption-partial resorption out-of-phase configuration*

1. Working principle: A simplified schematic of the arrangement is shown in Figure 1, this arrangement consists of two adsorbent beds, a refrigerant receiver, a condenser and an evaporator. In this arrangement, it is envisaged that the adsorber and disorber operate out of phase but continuously by combining the two processes. As the pressure of the desorber is being raised to that of condenser due to heating, desorption of the adsorbate is being initiated. The desorbed high pressure gaseous adsorbate enters the condenser through one-way valve, DC, and is liquefied and collected into the receiver. This adsorbate passes through the throttling device and enters the evaporator as a low pressure liquid adsorbate. Later, it begins to boil due to heat gain from the evaporator load and consequently, as the adsorber pressure reaches that of the evaporator, it gets adsorbed through one-way valve, AE, by the adsorbent in the adsorber thereby producing cooling in the evaporator. This absorbate later get re-absorbed into the desorber for another cycle. It is envisaged that part of the boiling adsorbate would move back to the desorber through one-way valve, DE, through diffusion process.

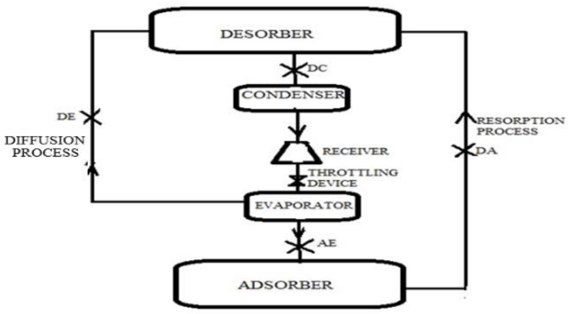

Figure 1 Schematic of proposed design arrangement 1

2. Merits and limitations: The integration of adsorption and resorption processes in a single system is a significant advantage as this approach allows for improved energy utilization and enhanced system performance. This combination ensures a continuous and cyclic operation, optimizing the overall cooling/heating process. In addition, the utilization of separate beds for adsorption and desorption, without substituting their functions, is important in ensuring effective heat transfers as they are dedicated to their respective roles. This leads to stable and reliable system performance, avoiding potential issues that might arise from bed substitution during the cooling/heating cycle. The described configuration, though, is still mechanically complex as isolation of different processes and components will require opening and closing many valves which are prone to premature failure and fluid leakage. Importantly, the major drawback of this design is that there will be partial resorption process of the adsorbate into the desorber. This is because heating of the adsorber is still needed to regenerate. Hence, the desorber and the adsorber are not totally out of phase.

B. Design arrangement 2: The rotary desiccant wheel configuration

1. Working principle: Figure 2 illustrates a configuration where a desiccant wheel is divided into two sections: the adsorbing and desorbing sections. In this setup, the low-pressure and low-temperature adsorbate vapour from the evaporator is introduced into the adsorption section of the system. The transfer of the adsorbate releases heat during the adsorption process. The continuous rotation of the desiccant wheel allows the saturated section of adsorber to enter the desorption section and release the absorbate and the equivalent disrobed section to enter the adsorption section again, creating a full cycle of adsorption and desorption. The desorbed adsorbate then enters the condenser, where it is cooled and its temperature is subsequently reduced. The high pressure adsorbate enters the evaporator through an expansion valve reducing its pressure and temperature which allows it to absorb heat from the evaporator. The low-pressure adsorbate vapour from the evaporator, in turn, re-enters the adsorption section, initiating another adsorption cycle. While this arrangement offers design merits, it also presents certain limitations.

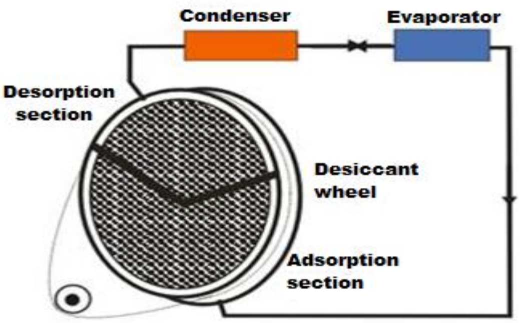

Figure 2 Schematic of proposed design arrangement 2

2. Merits and limitations: The proposed design arrangement presents several noteworthy credits that improve energy performance. For example, the integration of a rotary adsorbent bed enables continuous and uninterrupted adsorption and desorption processes, enhancing the overall system performance. It also eliminates the need for complex valves for refrigerant and hot/cold fluid, simplifying the system's mechanical components. Equally, the self-regenerating capability of the system eliminates the need for a circulating heating or cooling medium, streamlining the design and reducing energy consumption. Additionally, the continuous adsorption and desorption processes ensure a consistent and stable cooling output with low-energy continuous wheel rotation mechanism which contributes to improved energy efficiency.

On the other hand, one of the major likely drawbacks is sealing issues. That is, separating the low pressure region from the high pressure one. In addition, since the system is anticipated to be self-regenerating, there will be a high demand for thorough insulation and airproofing in order for the energy released at the adsorption section of the wheel to be optimally retrieved at the desorption section. Another likely drawback is the use of external transmission equipment for the rotation of the adsorbent wheel.

C. Design arrangement 3: Desiccant-circulator-aided fluidised adsorbent bed

1. Working principle: In this configuration, the utilization of a fluidized adsorbent bed is considered, where the solid adsorbent undergoes continuous movement between the heat source (for heating/desorption) and the heat sink (cooling/adsorption), as depicted in Figure 3. This innovative approach enables an uninterrupted operation, facilitating both cooling and heating processes continuously. However, the main technical challenge is in devising a cost effective method to circulate the solid desiccant without compromising its strength and structural integrity. Overcoming this difficulty will be essential for fluidized adsorbent bed arrangement for efficient and reliable cooling and heating applications.

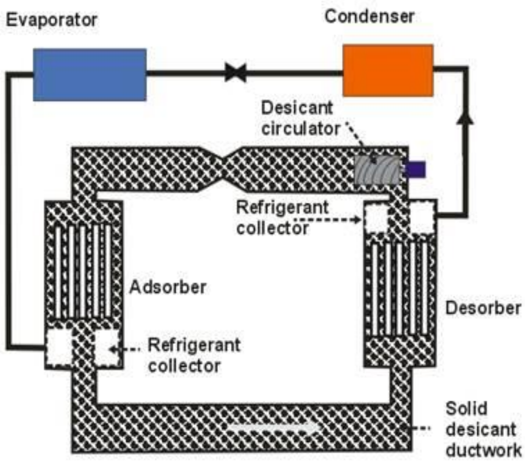

Figure 3 Schematic of proposed design arrangement 3

2. Merits and limitations: This arrangement eliminates complex use of control valves for refrigerant and hot/cold fluid flows for the adsorption and desorption process, reducing potential points of failure and increasing system reliability. In addition, the localization of the heat source and heat sink heat exchangers ensures effective heat transfer in the adsorber and desorber beds. The use of circulating motor/vane mechanism of the solid desiccant increases the system reliability but equally, it could lead to mechanical failure and requires frequent maintenance. Moreover, this may prove challenging to sealing the refrigerant as well as achieving separation of low-pressure and high-pressure regions within the system. The continuous movement of the desiccant may lead to the possible deterioration of the desiccant materials over time through friction, necessitating careful material selection and monitoring. Lastly, there is a risk of entrainment of solid desiccant particles into the condenser/evaporator circuit, which could cause fouling of the heat exchangers and impact the system's functionality and require appropriate filtration.

IV. CONCLUSIONS

Presented in this paper is the critical appraisal of the various possible alternative innovative configurations of adsorption solid desiccant cooling/heating systems geared towards enhancing the current status of the technology. In the quest to fill the identified research gaps in the literature, three innovative configurations have been presented with the credits and limitations of each critically evaluated. The main design innovation considered in this work relates to the way in which the solid desiccant is circulated hermitically between the heat source and heat sink. Therefore, the concept of the configurations in this work with their pertinent potentials (which include continuous cold production, eradication of the issue of unnecessary load on the evaporator, maximum optimization of both adsorption and desorption processes due to the spatial separation of both desorber and adsorber, absence of thermal stress induction in the bed as heat source and heat sink heat exchangers are localised) is intended to overcome the aforementioned identified bottlenecks often encountered by adsorption cooling technology. This appraisal is aimed to provide the required impetus for fast tracking the further development and wider application of adsorption cooling technology.

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