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Research Paper

Role of desorption route in a novel single-column continuous solid sorption cooling process

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HIGHLIGHTS

- Creating differential temperature across the length of single adsorbent column.
- Cooling depends on the route followed by the gas during desorption.
- Desorption through both ends of column generates the highest temperature gradient.
- Orifice opening has significant impact on the cold end temperature creation.

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ABSTRACT

The occurrence of quick and successive pressurisation and depressurisation in a single adsorbent column has been found to generate differential temperature between the two ends of the tube. This enables thermal linking of the two ends of the bed permanently with heat sink and heat source. The magnitude of the temperature differential depends on multiple parameters, namely, adsorption capacity, heat of adsorption (or desorption), adsorbent particle density, operating pressure, cycle time, etc. It has also been learnt that the existence of an orifice at the hot end of the column can magnify the temperature differential substantially. This impression has been slightly renewed in view of the recent experimental studies involving all possible valve arrangements for the adsorption and desorption to take place. During adsorption, the orifice valve creates pressure drop across the two ends. But during desorption, it needs to be ensured that desorption occurs through both ends of the column. In-depth theoretical analysis correlating transient heat and mass transfer equations could predict the experimental thermo-hydraulic observations reasonably. The energy distribution among the various elements, namely, adsorbate, adsorbent, convective heat flow or heat exchange between adsorbent and wall, has been studied theoretically. Finally, performance analysis has also been done.

1. Introduction

Sorption cooling, in the future, may become a potential alternative for creating ‘green refrigeration’ due to the environment-friendly nature of the adsorbate–adsorbent pairs used in the process. While the liquid-sorption cooler technology is quite matured and the coolers are already available commercially in the market, development of solid sorption cooling is relatively newer yet promising [1]. In order to make sorption cooling processes (irrespective of solid or liquid) commercially viable, enhancement in the overall cooling performance and simultaneous reduction in operational complexity are mandatory [2]. Incorporating modifications in the sorption processes [3–6] or attempting different combinations of sorbate–sorbent [7–10], researchers have tried to overcome the limitations.

In the renewable or waste heat driven liquid-sorption cooling systems, the adsorbent creates necessary pressure swing, while cooling is achieved by *evaporation of the refrigerant* [11]. These heat driven systems have the advantage of using renewable or waste heat, but the second law of thermodynamics imposes restriction on their thermal efficiency [12]. On the contrary, in the ‘mechanical compressor driven sorption cooling’ process, one has the benefit of using the electricity directly. In this process, cooling is no longer achieved by the evaporation of refrigerant; instead the *heat of desorption* provides the necessary *refrigeration*. Moreover, some of the gases inappropriate for the thermal compressor driven system due to high vapour pressure can find application in the mechanical compressor driven systems. Possible use of different adsorbent–adsorbate pairs has also been verified [13–15].

Operational complexity in sorption cooling processes, irrespective of the types, amplifies with the use of multiple beds essential to make the intermittent processes continuous [16]. Connecting the adsorption column to heat sink and heat source in every half cycle

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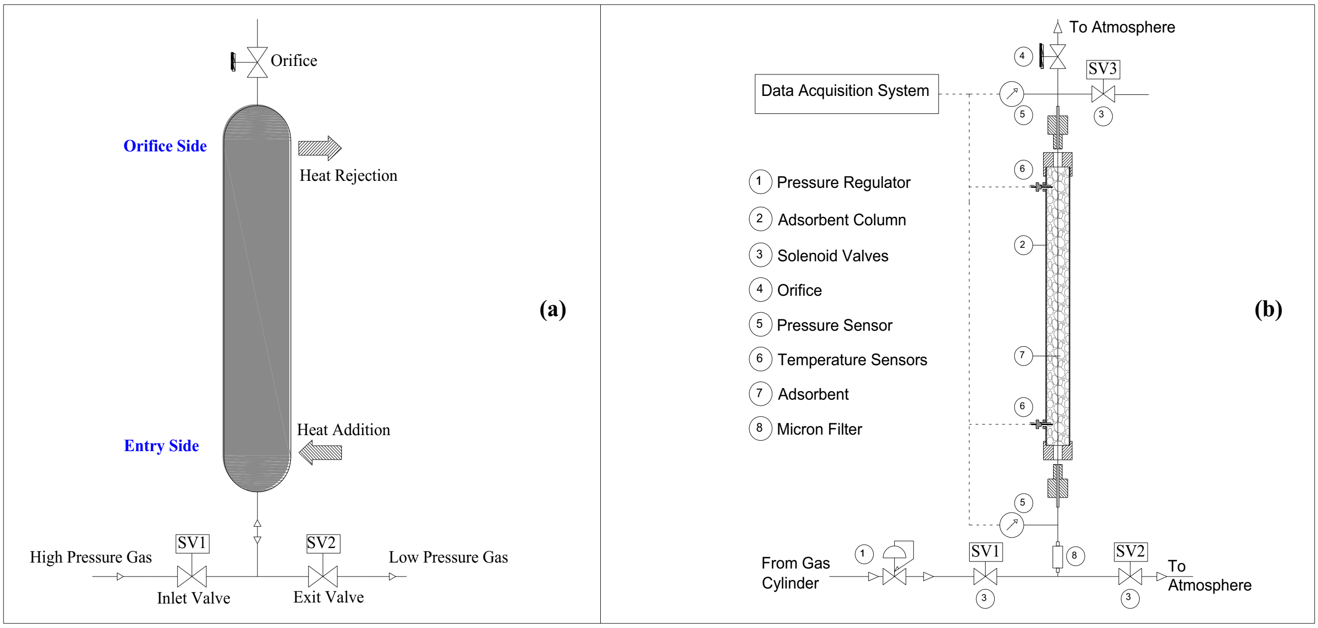

Fig. 1. Schematic of the single column continuous sorption cooling (a) process, (b) experimental setup.

is invariably a negative aspect needing attention. Primarily with the objective of reducing the operational hazards in the 'mechanical compressor driven' systems, Koley and Ghosh [17] described a method where sequential and quick pressurisation and depressurisation of the adsorbent bed have been found to generate differential temperature across the two ends of a single adsorbent column. It enables the hot end to connect permanently with the heat sink and the other end to heat source. Considerable reduction in the operational hazards can be achieved by this process (Fig. 1).

According to the proposed sorption cooling technique, adsorption occurs quickly through an inlet solenoid valve (keeping the exit valve closed). After a certain interval of time, the role of the valves is interchanged. Closing the inlet valve, exit solenoid is opened. Desorption takes place through the exit valve. When the process occurs in quick succession, temperature gradient has been found generating between the two ends of the column.

If a small opening is provided at the opposite side of gas entry to the column, temperature gradient between the two ends becomes larger. In practice, a regulating valve has been used to act as an orifice. Orifice always remains open (irrespective of adsorption or desorption cycles), causing significant impact on the temperature and pressure profiles. Koley and Ghosh [18] have performed extensive experimental studies using activated carbon–nitrogen as the adsorbent–adsorbate pair. Theoretical model has also been developed to understand the physics and to explain the experimental findings. The effect of orifice opening on the cold end temperature has been tested experimentally [18].

Sorption cooling being strongly dependent on the way adsorption or desorption occurs in the adsorbent column, all possible combinations of 'valves in operation' have been investigated, both theoretically and experimentally in the present article.

2. Probable valve configurations

In order to differentiate the two ends of the column, let us call the end of the tube through which gas enters the adsorbent bed as ***entry*** side. The other end can be referred to as ***orifice*** side.

Verifying all probable sensible combinations for the adsorption and desorption routes, three alternatives have been found *meaningful* (Fig. 2). Assuming that the adsorbent bed is ***always*** pressurised through *entry side*, the possible desorption route could be through:

i) ***both*** ends (i.e. entry and orifice sides) of the column (Fig. 2a).
ii) the ***opposite*** end (i.e. orifice side) of the column (Fig. 2b).
iii) the ***same*** end (i.e. entry side) of the column (Fig. 2c).

According to Fig. 2a, gas desorbs *mainly* through the entry side solenoid valve and *partially* through the orifice valve. Desorption, in this arrangement, thus occurring simultaneously through both ends of the column can be called bidirectional. However, for the remaining two arrangements (Fig. 2b and c), desorption is unidirectional. In case of 'dead end' pressurisation–depressurisation (Fig. 2c), adsorption and desorption both occur through the entry side. Unilateral desorption is also possible in another situation when depressurisation is allowed completely through the orifice end (Fig. 2b).

In the following sections, details of the test setup and the outcome have been elaborated.

3. Experimental

The experimental setup has been fabricated according to the schematic shown in Fig. 2.

Instead of performing the experiments in a closed loop condition using a mechanical compressor, the gas supply in the present test setup has been arranged from high pressure gas cylinders (not shown in the figure). The desorbed gas is vented to atmosphere. In all situations, pressurised gaseous nitrogen enters the adsorbent bed through the entry side solenoid valve (SV1) in open condition. The state of the orifice valve has always been maintained in the open condition (Fig. 2a and b), except in the case of 'dead-end' filling-emptying (Fig. 2c). But, the way desorption occurs in the various arrangements shown is essentially different.

In the configuration shown in Fig. 2a, desorption occurs simultaneously from *both ends* of the tube. In this case, outflow of the desorbed nitrogen gets distributed through the two ends depending on the orifice opening and the coefficient of the solenoid valve