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Novel operational strategy for operating a hybrid mechanical compression and adsorption based chiller#

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ABSTRACT

Catering to variable load has been a big challenge for large chillers for air-conditioning and process cooling applications. Traditionally chillers were designed for catering to peak capacity with hot-gas bypass being the most common technique for capacity control in fixed speed operation. In more recent applications variable speed compressors have been the preferred choice. In this study we propose a novel hybrid system which combines the mechanical and thermal compression techniques for producing chilled water. The mechanical compression caters to steady load whereas the adsorption based thermal compression caters to variable load. The refrigerant used in this study is R134a with coconut shell based activated carbon as the adsorbent. The adsorber connects to evaporator under peak load operation whereas it regenerates during low load condition thereby keeping the chilled water outlet temperature nearly constant. Experiments are conducted on a lab-scale 1 RTon system. The proposed operational strategy has the potential to handle up to a 26% variation in refrigeration load on the evaporator for maximum regeneration temperature of 85^{0}C for the adsorbent.

Keywords: vapor compression systems, adsorption cooling, activated carbon, hybrid cooling system.

NONMENCLATURE

Abbreviations	
Adhx	Adsorption heat exchanger
Ads	Adsorption
CSAC	Coconut shell based activated carbon
Des	Desorption
OM1	Operational mode one
OM2	Operational mode two
Pc	Precooling
Ph	Preheating
VAds	Vapour adsorption refrigeration
VCR	Vapour compression refrigeration

1. INTRODUCTION

The cooling requirement in the present day has become ubiquitous; whether it is for comfort cooling or food processing, demand for these systems is ever-increasing, and energy consumption associated with these equipment is a cause for concern. These are causing significant stress on the electricity grid. Efforts are being made to decrease the energy consumption of these systems, which include systems that operate on waste heat and systems that can work efficiently by controlling the capacity of the system based on demand, thereby decreasing energy consumption. Primary methods for capacity control include on/off capacity control, compressor unloading (in case of multiple compressors) [1], hot gas bypass method [2–4], digital scroll capacity control [5], and variable speed capacity control [6]. For fixed capacity reciprocating compressors, generally, on/off capacity control, compressor unloading, a hot gas bypass method, or a combination of both is applied [7,8]. The hot gas bypass method and compressor unloading offer limited capacity control ranges for the VCR systems [6],[9].

The present work explores a hybrid configuration based on a combination of vapour compression refrigeration (VCR) and vapour adsorption cooling (VAds) system in parallel mode, thereby sharing the same refrigerant circuit as shown in Fig. 1. Where the VAds system utilizes heat from the industrial baking ovens, where waste heat is available in the form of flue gases in the range of 120-150^{0}C [10,11]. The proposed system is designed to utilize the in-house waste heat that is available in the industries and supply their variable cooling demand with the combination of VCR and VAds systems. The design of the VCR system is based on the base load, while the VAds system is designed to cater to additional peak load for a short duration of time. The present system is capable of operating in different modes. An earlier published work discusses its first operational mode, where additional cooling demand during peak hours is met [12]. The present work

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discusses its second operational mode, where capacity control operation is performed.

existing technologies but to provide an alternative option for capacity control based on usage and

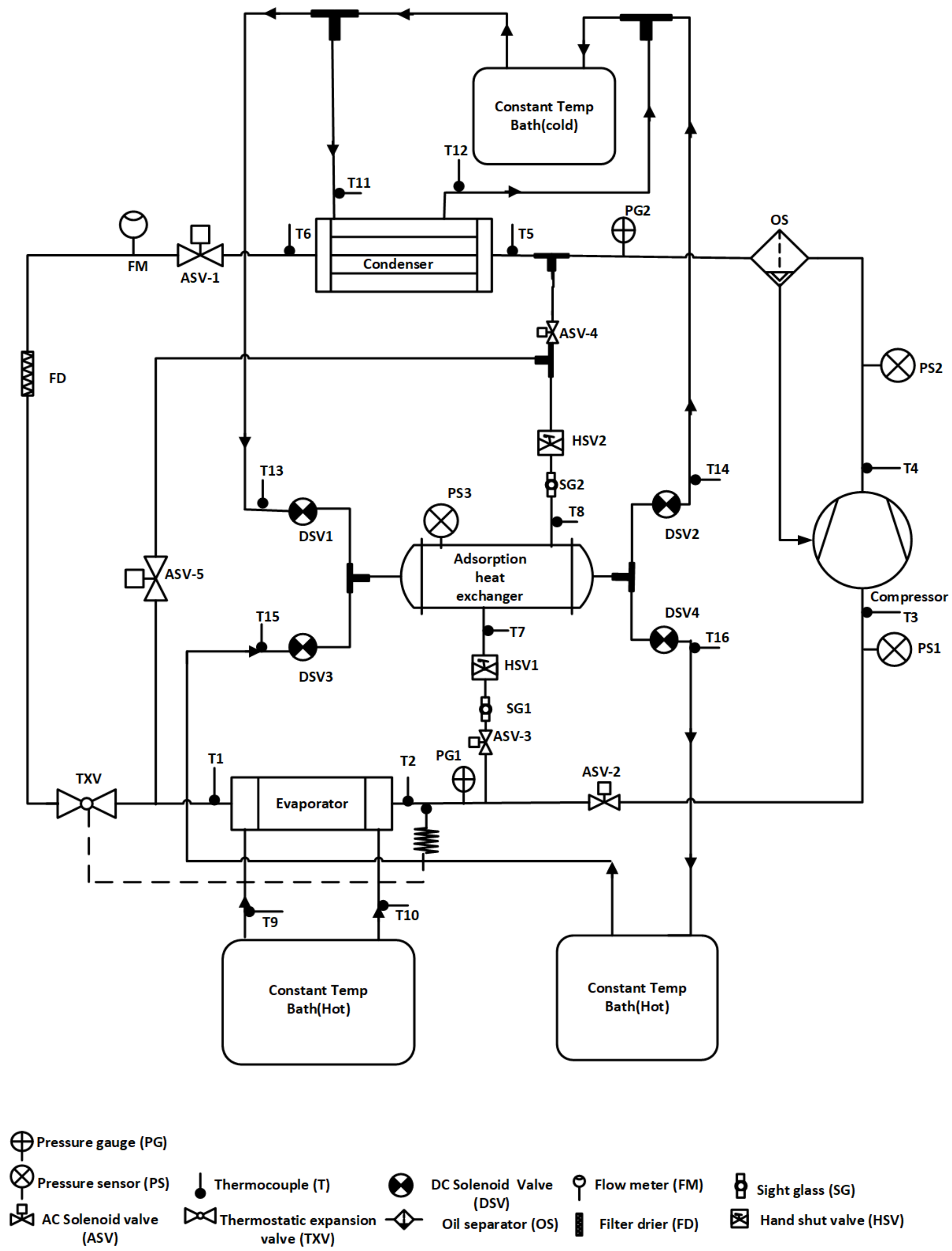

Fig.1 Schematic of Experimental setup

The present work is unique in the sense that it is the first experimental effort to combine the VCR and VAds systems in parallel mode. It utilizes the waste heat available in-house, thereby reducing industries' carbon footprint. It can operate in multiple modes when operating in a hybrid configuration, due to which it can either augment the cooling capacity over and above the capacity provided by VCR system or perform function of capacity modulation, during weak demand periods. Present proposed setup is not meant to replace the considering suitability of application.

2. EXPERIMENTAL SETUP DESCRIPTION AND OPERATION

Fig.1 above presents the schematic of the experimental setup built at refrigeration and air conditioning laboratory of Indian Institute of Technology Kharagpur. Setup consist of shell-n-tube type heat exchanger working as evaporator, condenser and adsorption heat exchanger. Adsorption heat exchanger

(Adhx) is packed with coconut shell based activated carbon, between tube bundle, tube bundle is held together by tube sheet and fins placed at constant pitch. Whole assembly is held together by a fine mesh. A single speed reciprocating compressor is also used in VCR line from Embraco©. Refrigerant used in the system is R134a, reason being it is still very much in use in VCR system in the developing countries [13] and it is one of fluorinated refrigerant whose uptake and kinetic studies [14–19], have been studied widely. Hand shut valves in addition to solenoid valves are provided at the inlet and exit of Adhx, to isolate the Adhx during standalone operation of VCR system. System can also work as standalone VAds system, but provides poor cooling capacity due to evaporator behaving as oversized for a single Adhx acting alone as a thermal compressor. In hybrid mode Adhx adsorbs from evaporator and then can either desorb it to condenser (defined as operational mode one (OM1)) or can desorb it to evaporator (operational mode two (OM2)).

In present section system's operational mode two is explained. For the steady load operation standalone VCR system works and when capacity reduction is required system enters in to the OM2. During OM2, ASV3 opens and refrigerant from evaporator enters in to the Adhx, while it is continually cooled, by circulating cold water from cold constant temperature bath while DSV1 and DSV2 are open. The process continues for a duration known as adsorption time. After adsorption process system enters into preheating stage and Adhx is heated with the help of hot water circulated using hot constant temperature bath. During this process all the inlet and exit valves to the Adhx are closed and constant volume heating process takes place inside the Adhx. DSV1 and DSV2 are closed while DSV3 and DSV4 are open. When the Adhx pressure rises by one bar from the evaporator pressure the discharge side valve, ASV5 is opened. Which discharges the refrigerant gas to the evaporator due to which a ghost load is applied on the evaporator which is the main cause for capacity reduction. This process continues for the predefined amount of time known as desorption process. During this time also bed is supplied with the hot water. After this process DSV3 and DSV4 are closed along with ASV5, and DSV1 andDSV2 are opened and cold water is circulated through the Adhx. This process continues till the pressure inside the Adhx is less than evaporator pressure by one bar. This process is called precooling. After precooling ends system again enters adsorption stage and cycle continues. During all these processes compressor keeps running. Table.1. present the valve operation for the OM2.

Mode	Valves Operation							
	ASV1	ASV2	ASV3	ASV5	DSV1	DSV2	DSV3	DSV4
VCR	1	1	0	0	1	1	0	0
VCR+Ads	1	1	1	0	1	1	0	0
VCR+Ph	1	1	0	0	0	0	1	1
VCR+Des	1	1	0	1	0	0	1	1
VCR+Pc	1	1	0	0	1	1	0	0

Table. 1. Valve operation sequence in OM2 (0=close; 1=open)

3. RESULTS AND DISCUSSION

This section discusses the initial results obtained from experiments performed on the experimental setup. Experiments are performed for regeneration varying from 60 to 85^{0}C. While chilled water inlet temperature is kept at 22.5^{0}C, and condenser and Adhx cooling water is kept at 30^{0}C. Experiments are performed for two set of adsorption and desorption time i.e. 700s and 1000s. Switching time is calculated based on the pressure that is achieved by the Adhx. Fig.2, 3, & 4 presents instantaneous performance of the hybrid system when compared with standalone VCR system, for one cycle of operation when hybrid system has reached cyclic steady state. Regeneration temperature is kept 65^{0}C, and ads/

des time is kept at 700s for the analysis. Fig.2. presents the variation of chilled water outlet temperature for hybrid and Standalone VCR system, when chilled water inlet temperature is kept same for both the condition. It can observed that when hybrid system is in operation

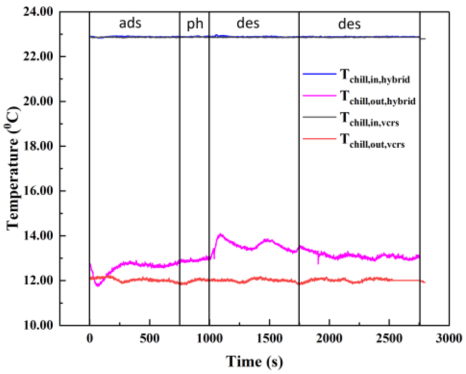

Fig.2 Variation of chilled water temperature with time

chilled water outlet temperature rises due to mixing of throttled refrigerant from the TXV and desorbed refrigerant from the Adhx, resulting in higher temperature of refrigerant entering the evaporator, thus more gaseous refrigerant results in the reduced performance of the evaporator.

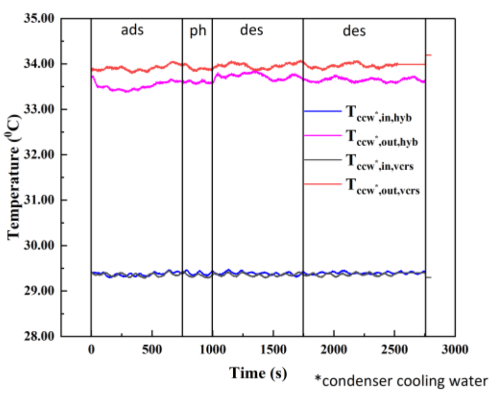

Fig.3 Variation of condenser cooling water with time

Fig.3 shows the variation of condenser cooling water with time for hybrid and VCR system. Condenser cooling water temperature for hybrid system is slightly less than that for the VCR system, which also lead to marginal improvement in compressors power consumption since a part of mass flow rate from VCR circuit is diverted to Adhx, thus leading to a lower load on the condenser.

Fig.4 below shows the variation of refrigeration capacity with time, it can be observed that refrigeration capacity of hybrid system is highest when system enters the adsorption stage and is lowest when it enters the desorption stage, which is expected since when adsorption start a large amount of refrigerant exits from the evaporator which lowers its temperature and a small boost in the refrigeration capacity is observed. When system enters the desorption stage hot refrigerant is desorbed into the evaporator due to which amount of liquid refrigerant in the evaporator decreases thereby gaseous refrigerant acting as a ghost load on the evaporator reduces its capacity.

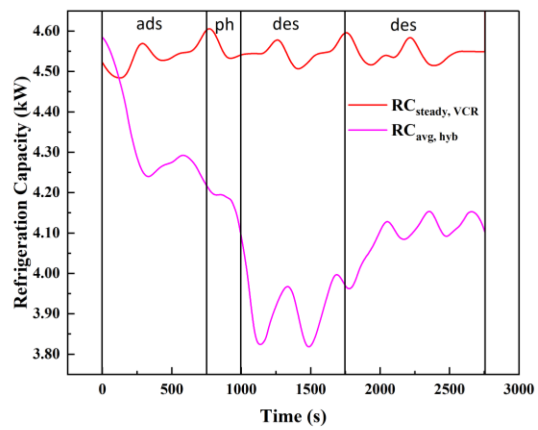

Fig.4 Variation of refrigeration capacity for hybrid and VCR system with time

Fig.5 presents variation of refrigeration capacity ratio, which is defined as ratio of refrigeration capacity of hybrid system averaged over cycle time with the steady state refrigeration capacity of standalone VCR system. It can be observed that as regeneration temperature increases refrigeration capacity first increases and then decreases, due to which ratio also follows the same trend, since refrigeration capacity of VCR system is almost constant during standalone operation. Since at low regeneration temperature desorption is poor, which lead to insufficient adsorption in the successive cycle, thus bed desorbs whatever refrigerant it already had adsorbed during last operations and there is a decrease in the overall refrigeration capacity. As regeneration temperature increases adsorption improves and thus there is a rise in refrigeration capacity of hybrid system.

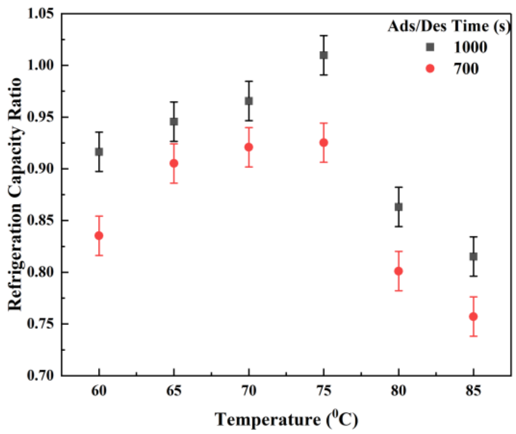

Fig.5 Variation of refrigeration capacity ratio with regeneration temperature

Which also results in higher refrigeration capacity ratio, this peaks at about 75⁰C for both the cases. As regeneration temperature rises further refrigeration capacity ratio decreases and a maximum decreases by ~26% is observed when regeneration temperature rises up to 85⁰C. It is due to the fact that temperature of desorbed gases entering into the evaporator rises further due the higher regeneration temperature.

4. CONCLUSIONS

Experiments were performed on a lab-scale experimental setup of 1 RTon of nominal capacity. Hybrid system can operate in multiple mode, its operational mode two is discussed here, which is designed to handle capacity variation. Initial finding are discussed in the paper which shows that system can be used to handle slight load in variation which ranges up to ~26%. Future work involves optimization of cycle time for the system operation.

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