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Research Paper

Experimental investigations and modelling of a small capacity diffusion-absorption refrigerator in dynamic mode

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HIGHLIGHTS

- Dynamic operation of a small capacity commercial diffusion-absorption refrigerator is experimentally investigated.
- A first order transfer function is used to describe the relationship between the driving power and the cooling capacity.
- A generalized dynamic black-box model for the DAR refrigerator is developed using Matlab Simulink® environment.
- The predictions made by the model for steady-state *COP* are well in agreement with experimental data.

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ABSTRACT

This paper reports on the experimental investigations in a non-steady state mode of a small capacity commercial diffusion-absorption refrigerator (DAR) and the development of a dynamic black-box model for the machine. For these investigations, the refrigerator was equipped with the appropriate metrology. Temperature time variations of the refrigerated room and of the ambient conditions were measured, monitored, and stored using a data acquisition unit connected to a computer. A standardized experimental procedure was used to determine the overall heat conductance of the refrigerated room: A value of $(UA)_{cab} = 0.554\ \mathrm{W\,K^{-1}}$ was found. The time evolution of the cooling capacity for different driving heat inputs to the refrigerator was investigated. Based on the experimental data, a dynamic black-box model was developed using the Matlab identification package to correlate the power input to the generator and the cooling capacity of the refrigerator. A first order transfer function with a delay was found to describe quite accurately the time evolution of the cooling capacity for all considered heat rates supplied to the generator. In a further step, regressed analytical expressions of the transfer function parameters, as a function of the generator heat supply, were incorporated into the cooling capacity function. A generalized dynamic black-box model for the DAR system was thus obtained and was then validated using the Matlab Simulink® environment. The predictions made by the model were found to be well in agreement with the experimental data. In particular, the predictions for *COP* under steady state conditions agreed satisfactorily with the experimental data yielding a maximum relative deviation of about 8%.
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1. Introduction

Diffusion-absorption refrigeration (DAR) systems are widely used in supermarkets, domestic freezers, and hotel rooms, etc. This technique for producing cold was patented in 1928 by the two Swedish engineers, Von Platen and Munters [1]. The unique feature of the DAR cycle, compared to a conventional ammonia-water absorption cycle, is that it operates at a uniform pressure. The working fluid is a mixture of three components: ammonia as a refrigerant, water as an absorbent, and an auxiliary inert gas, frequently hydrogen or helium. The inert gas is necessary to reduce the partial pressure of the refrigerant in the evaporator, and allow for it to evaporate at low temperatures and for the production of useful cold. DAR systems are silent because they have no moving parts.

Over the years, investigations have been published on the performance of various configurations of DAR cycles using graphical, numerical and experimental approaches. Kouremenos and Stegou-Sagia [2] investigated the use of helium as an alternative to hydrogen. The authors observed a similar behaviour of both inert gases. Zohar et al. [3] developed a thermodynamic model

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Nomenclature

COP	coefficient of performance (–)	τ_d	time delay (s)
$F(t)$	unit step function (–)	θ_p	time constant (s)
G_R	transfer function (–)	φ	applied voltage (V)
K_P	static gain (–)		
$\dot{Q}_{gen}$	generator heating power (W)	*Subscripts*	
$\dot{Q}_{heat}$	electric cable heating power (W)	*amb*	ambient
$\dot{Q}_f$	cooling capacity (W)	*cab*	refrigerated room
R	resistance of the electric cable (Ohm)	*elec*	electric
s	laplace variable (–)	*evap*	evaporator
T	temperature (°C)	*int*	interior
t	time (s)		
U, Y	laplace transform of input and output (–)		
(UA)	overall heat conductance ($W\,K^{-1}$)		

for an Electrolux DAR system and analysed its performance with both inert gases and found that the *COP* of the system operating with helium was 40% higher than that of the system operating with hydrogen. They further reported that higher *COP* values were obtained by using an ammonia mass fraction of 30% in the rich solution and of 10% in the weak solution. Zohar et al. [4] compared the configurations of a DAR cycle both with and without condensate sub-cooling prior to the evaporator entrance. They showed that in the DAR cycle without sub-cooling there was a 14–20% higher *COP* than in the DAR cycle with condensate sub-cooling. Zohar et al. [5] examined numerically the performance of a DAR system operating with the organic absorbent DMAC which was associated to five different refrigerants and with helium as an inert gas. They compared the performance of their systems with that of the system operating with ammonia-water and helium and found out that the latter had the highest *COP* values. Ben Ezzine et al. [6] investigated the feasibility of a DAR system operating with the working fluid system DMAC-*R*124-He and coupled to a solar collector. They reported that both the *COP* and the temperature of the cooling effect depended largely on the effectiveness of the absorber and the generator temperature. For solar cooling applications, this working fluid mixture could be an alternative to the conventional ammonia-water-hydrogen mixture. Starace and De Pascalis [7] developed an enhanced thermodynamic model to consider the more realistic operating conditions of the DAR cycle, such as the presence of some water (absorbent) in the refrigerant stream (ammonia). They used a magnetron activated thermal pump in order to reduce the start-up time of the refrigerator. The model's predictions were validated on a prototype built by coupling a domestic magnetron to a small purposely modified commercial DAR. A maximum deviation was noticed to be roughly 2% in the weak solution mass flow rate and lower than 5% in the *COP* between the predicted and measured data. Sayadi et al. [8] presented a HYSYS simulation model for a water-cooled DAR system using different binary mixtures of light hydrocarbons (C_3/*n*-C_6, C_3/cyclo-C_6, C_3/cyclo-C_5, propylene/cyclo-C_5, propylene/*i*-C_4 and propylene/*i*-C_5) as working fluids and helium as an inert gas. The driving heat in the generator was supposed to be supplied by evacuated tube solar collectors. The most appropriate binary mixture was found to be C_3/*n*-C_6 with a generation temperature of 126 °C. Long et al. [9] investigated numerically the possibility of using TFE-TEGDME in the DAR system together with two cooling mediums, namely water at 32 °C and ambient air at 35 °C. The authors performed a parametric analysis on the effects of the cooling medium, the generation and evaporation temperatures and the effectiveness of the absorber on the system performance. They compared the performance of the TFE-TEGDME and NH_3-H_2O DAR systems in terms of *COP* and circulation ratio. They concluded that the TFE-TEGDME mixture is a good working fluid for DAR systems and found that with an absorber effectiveness of 0.8, the optimum generation temperature for the air-cooled TFE–TEGDME DAR system is around 170 °C. A coefficient of performance (*COP*) up to 0.45 was obtained. However, the performance of the water-cooled system was better with a lower generation temperature of 130 °C and a higher *COP* of 0.56. Rodriguez-Munoz and Belman-Flores [10] presented a review on diffusion-absorption refrigeration technology in which over 70 publications were analysed. The authors concluded that diffusion-absorption technology represents an interesting and feasible alternative for small capacity refrigeration applications. Rattner and Garimella [11] proposed a fully passive DAR system operating with the working fluid mixture NH_3-NaSCN-He. Detailed design models for the various components of the system were elaborated. They reported *COPs* in the range of 0.11–0.26 at an ambient air temperature of 24 °C, low heat source temperatures of 110–130 °C and passive air cooling. These authors reported [12] on the development of a prototype of the theoretically investigated machine, activated by low temperature heat sources (110–130 °C) and passively air-cooled. The cooling temperatures achieved were suitable for refrigeration ($T_{evap} = 6 \rightarrow 3$ °C, *COP* ~ 0.06) and air-conditioning (12 → 8 °C, *COP* ~ 0.14; 18 → 14 °C, *COP* ~ 0.17). Chen et al. [13] improved the coefficient of performance of the DAR system by 50%. They modified the design and construction of the generator by integrating a tube-in-tube solution heat exchanger into the generator. Vicatos [14] studied experimentally a modified domestic DAR in order to reduce the response time of the system. Koyfman et al. [15] presented an experimental investigation on the bubble pump performance in a DAR system. They used a solution of an organic solvent and HCFC as refrigerant. Their results showed that the performance of the bubble pump depends mostly on the motive head and the heat input to the bubble pump. Jacob et al. [16] conducted a theoretical and experimental study on a solar driven ammonia-water diffusion-absorption cooling machine (DACM). They designed four prototypes for air-conditioning applications: water chillers with an evaporator temperature in the range of 6–12 °C and ceiling cooling with an evaporator temperature of 15–18 °C. The *COP* values achieved ranged from 0.10 to 0.45. Yıldız and Ersöz [17] designed a DAR system driven by electricity. They investigated numerically and experimentally the energy and exergy losses for each component of the system and compared the theoretical and experimental values. They concluded that the highest exergy losses took place in the solution heat exchanger. The experimental and predicted *COP* was around 0.19 and the exergy efficiency between 0.03 and 0.04. Mazouz et al. [18] studied experimentally a commercial DAR refrigerator in order to determine its performance under various operating conditions and developed a theoretical

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