IJCTA, 9(2-A), 2016, pp. 571-580

Response Dynamic Study of Various Components of a Diffusion Absorption Refrigerator Machine

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ABSTRACT

Dynamic modeling can be obtained by a theoretical approach based on physical laws (white-box) or experimental approach based on measurements taken on the system (black box). In the present work, a dynamic black-box models based on transfer functions of different components of a diffusion absorption refrigerator (DAR) machine was developed using MATLAB-Simulink software. For these investigations, a commercial DAR machine used as hotel mini-bar was equipped with measure instruments, the temperature at the inlet and outlet of each of its components were instantaneously measured and stored using a data acquisition system. Further, the obtained experimental results were used to perform a dynamic black box models for each components of the DAR. Developed models prediction results were validated with experimental data. The fitting quality, an indicator of the goodness of the models prediction results, ranges from 78 to 95%.

Keywords: Dynamic study, DAR Machine, MATLAB, Simulink, models prediction.

1. INTRODUCTION

Domestic vapor compression refrigerators are currently the most used. They utilize refrigerants which have proved damaging to the environment (ODP and GWP). In addition to these machines, there are diffusion absorption refrigerators. This kind of refrigeration systems was invented by the Swedish engineers Von Platen and Munters [1]. It uses ammonia as refrigerant, water as absorbent and hydrogen as inert gas. This refrigerator is well used as hotel mini-bar. It has no moving part, hence silent, and is usually powered on with electric heat but can also be powered with any heat source at the appropriate temperature.

Figure 1 presents the principle of this machine [2]. It consists of four main parts: the generator, condenser, evaporator and absorber. When heat is supplied to the generator, ammonia vapor separates from the water and rises to the rectifier (separator) taking with it weak solution. In the separator, the weak solution flows into the absorber and the vapor leaves to the condenser. The condensed and sub-cooled refrigerant meets hydrogen, coming from the absorber, at the inlet of the evaporator. The liquid ammonia begins to evaporate taking heat from the inside of the cabinet. The mixture of ammonia and hydrogen passes throw the gas-gas heat exchanger (GHX) and attends the absorber where the weak solution flows in counter-current with the ammonia-hydrogen mixture. The obtained strong solution continues to the generator [3].

Commercial refrigerators, compared with the diffusion absorption principle, contained a solution heat exchanger (SHX) and the GHX is used, also, to pre-cool the liquid refrigerant arriving from the condenser. In the SHX, the weak solution flows from the generator to the absorber and heats the strong solution passing from the absorber to the generator.

Most of the researchers involve the thermodynamic modeling with or without experimental tests. Koyfman *etal.* [4]presented an experimental investigation on the bubble pump performance in a DAR

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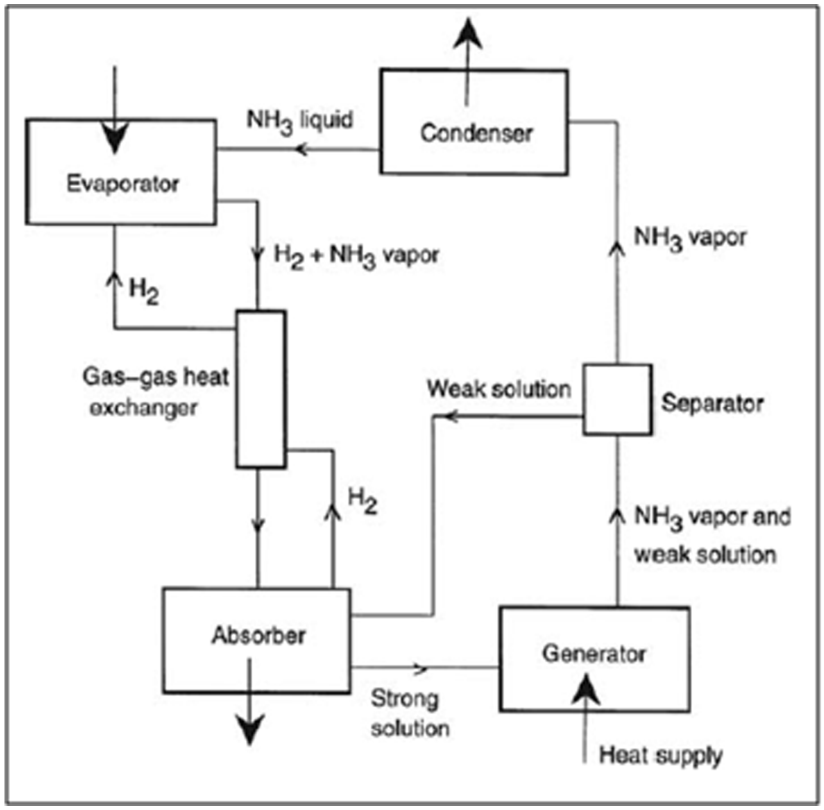

Figure 1: Schematic diagram of a diffusion absorption refrigerator

system. They used a solution of an organic solvent and a 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 *etal.*[5] 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 6-12°Cand ceiling cooling with an evaporator temperature of 15-18°C. The COP values achieved ranged from 0.10 to 0.45.Yýldýz and Ersöz[6] designed a DAR system driven by electricity as energy source. 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.[7] studied experimentally a commercial DAR refrigerator in order to determine its performance under various operating conditions and developed a theoretical simulation model of different DAR configurations. Some recent control methods are discussed in [12-15].

The dynamic behavior of this kind of units is neglected. In fact, dynamic models can be obtained by three different approaches: white-box, black-box and grey-box. The white-box method is based on physical laws that reflect the phenomena occurring in the studied system. Black-box approaches are purely empirical models, based on experimentation. From the available measurements, modeling is to relate the inputs and outputs of the system by equations with a number of parameters to be estimated. Grey-box is the combination of both theoretical and empirical approaches.

In this work, experimental investigations of a commercialdiffusion absorption refrigerator were carried out. A detailed black-box model predicting the dynamic response for each components of the DAR were presented using MATLAB-Simulink software. The models prediction results were validated with experimental data.

2. EXPERIMENTAL SET-UP

The studied refrigerator is a single compartment diffusion absorption system. It uses ammonia as refrigerant, water as absorbent and hydrogen as inert gas. This DAR machine was activated by a 63W electric heater. Sixteen K- Thermocouples were placed at the inlet and the outlet of each component. These thermocouples are related to a HP Agilent data acquisition system connected to a dedicated PC to monitor and store the measurements values continuously [8, 9]. The ambient temperature T_{ext} was also continuously measured and registered(see Figure 2).

The time evolutions of the input-output temperatures of the different components of the DAR machine are presented in Figure 3.

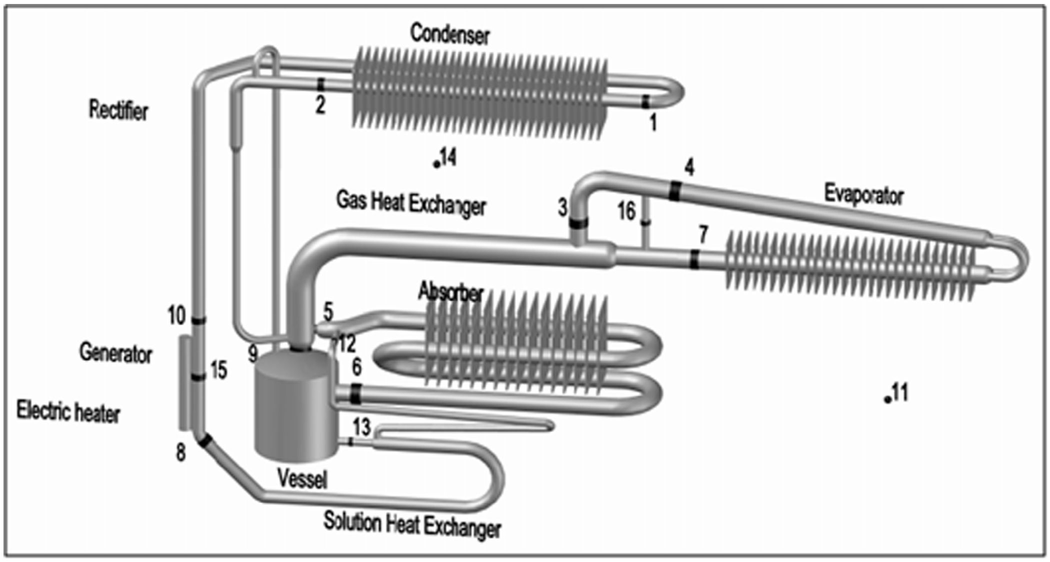

Figure 2: Refrigeration cycle and locations of thermocouples

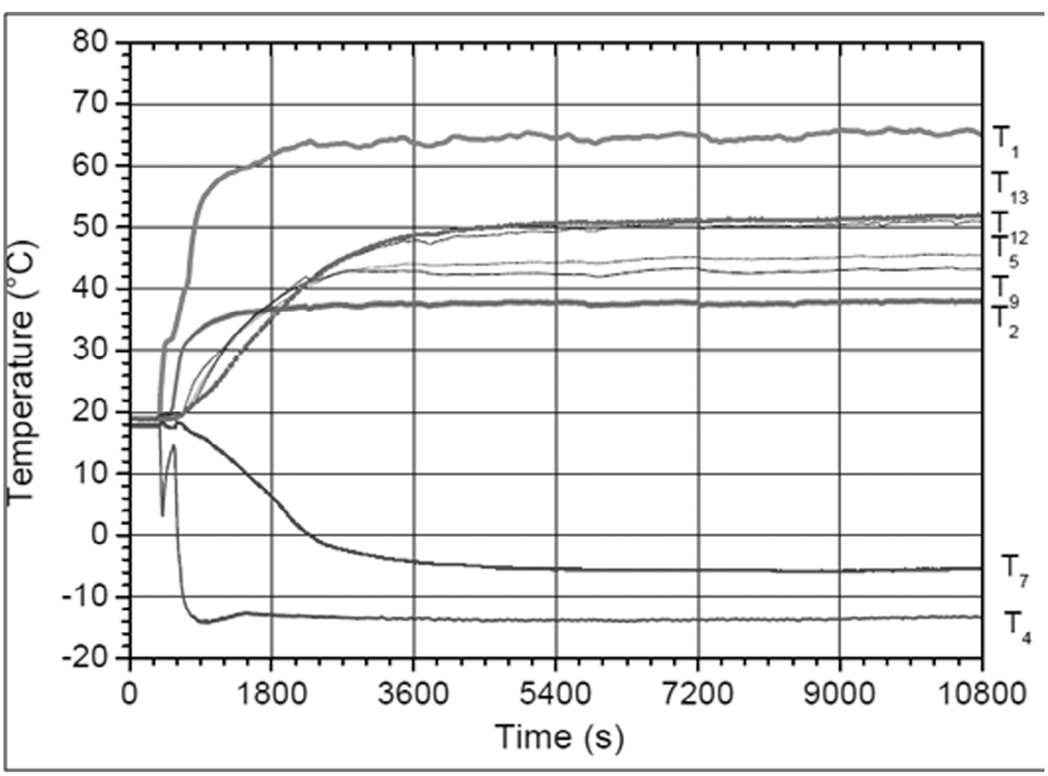

Figure 3: Evolution of the inlet and outlet temperatures of the different components

3. DYNAMIC MODELING

Dynamic modeling can be carried out either by theoretical analysis or experimental empirical approach based on measurements [10]. By using the database recorded on the machine during the experimental study presented in the previous section, an approach based on these results was developed to performdynamic modeling of the tested system.

A model is a mathematical descriptions of relations between the input and output variables of the system. Various methods are used to express these relationships. That based on the transfer functions and the Laplace transform is frequently used [11]. Figure 4 shows the response of a first order system with delay to a step unit [11]. The Laplace transform of the transfer function is written as:

$$G = \frac{K_p}{1 + T_p s} e^{-T_d S} \tag{1}$$

where K_p is the static gain, T_p the time constant and T_d the time delay.

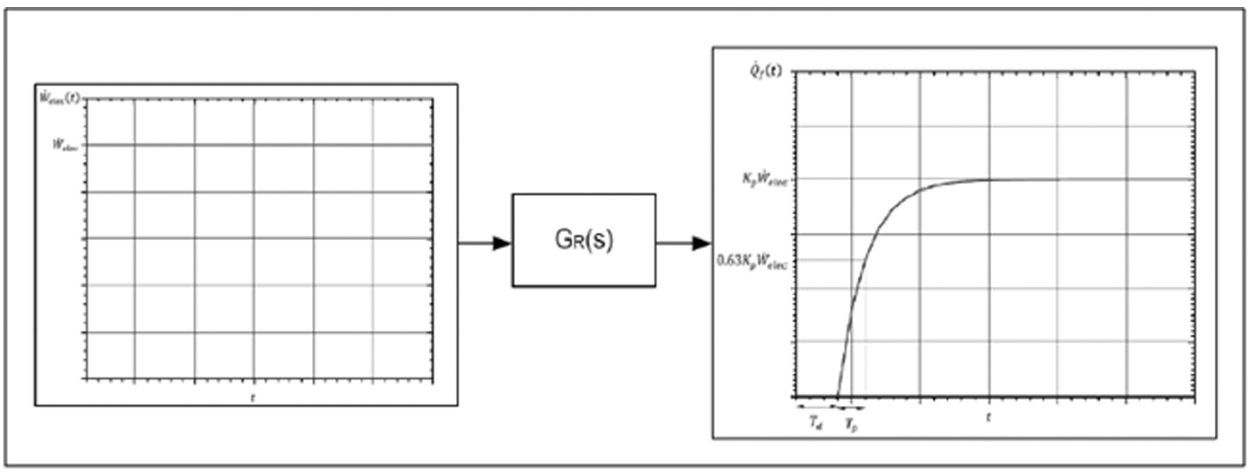

Figure 4: Step response of a first order system with delay

MATLAB-Simulink software was used to investigate the dynamic response modeling of each components of the DAR machine. Initially, the machine contains a rich ammonia-water solution occupying the reservoir, the generator and the circuit connecting them while hydrogen mixed with ammonia and water vapors constitutes the gas phase everywhere. By heating the generator, the fluids begin to flow in the refrigeration circuit, rectifier and condenser to reject some heat to ambient air and the evaporator, as a consequence, to cool the compartment of the refrigerator. At constant ambient temperature, the heat supplied to the generator is the only input parameter that affects the operation of the refrigerator. The input to the DAR machine was the electrical power $\dot{W}_{elec}$.

$$\dot{W}_{elec}(t) = \dot{W}_{elec} E(t) \tag{b}$$

where $E(t)$ is the step function.

4. RESULTS AND DISCUSSIONS

4.1. Generator-rectifier-shx

The generator initially containing the rich solution is heated using $\dot{W}_{elec}$ heat flow. The generator temperature increases which causes the separation of the rich solution to a vapor refrigerant and weak solution. The vapors continue their way to the air-cooled rectifier where a partial condensation takes place. The almost pure ammonia vapor moves on towards the condenser. The weak solution exit the generator, the solution heat exchanger and return to the absorber.

The modeling of this group of components consists on the determination of the relationship between the input of the system, $\dot{W}_{elec}$, and the outputs temperatures T1, T12 and T13. Let DT1, DT12, DT13 the differences between the temperatures T1, T12 and T13 and the ambient temperatures Text. Using $\dot{W}_{elec}(t)$ as input variable and DT1(t), DT12(t) and DT13(t) as outputs figure 5, the transfer function is of the form:

$$\begin{bmatrix} DT_1 \\ DT_{12} \\ DT_{13} \end{bmatrix} = G_{gen-rect-shx}\dot{W}_{elec} \quad \text{(c)}$$

$$G_{gen-rect-shx} = \begin{bmatrix} G_{DT1} \\ G_{DT12} \\ G_{DT13} \end{bmatrix} \quad \text{(d)}$$

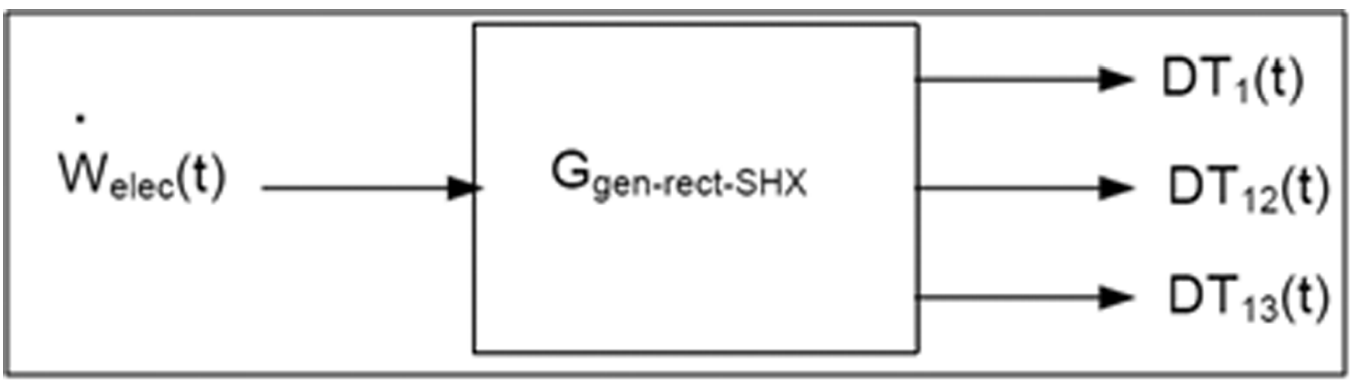

Figure 5: Diagram of the Generator-Rectifier-ShxModel

The parameters of the obtained transfer functions are presented in Table. 1

Table 1
Model parameters and performance indicators for the Gen-rect-SHX.

	K_p	T_p	T_d	*Fit (%)*
DT_1	0.72092	442.1	356.87	91
DT_{12}	0.49388	1216.9	607.47	95
DT_{13}	0.50914	1139.7	909.88	94

The temperatures T_1(t), T_{12}(t) and T_{13}(t) are obtained by a simulation using the Matlab Simulink® software. Figure 6 shows a comparison between the model prediction results and experimental measurements.

4.2. Condenser

In the condenser the vapor refrigerant at temperature T_1 is condensed to a sub-cooled liquid at T_2. The modeling of the condenser is to determine the relationship between the temperatures of the input and output streams (T_1 and T_2). The diagram of the model is shown in Figure 7.

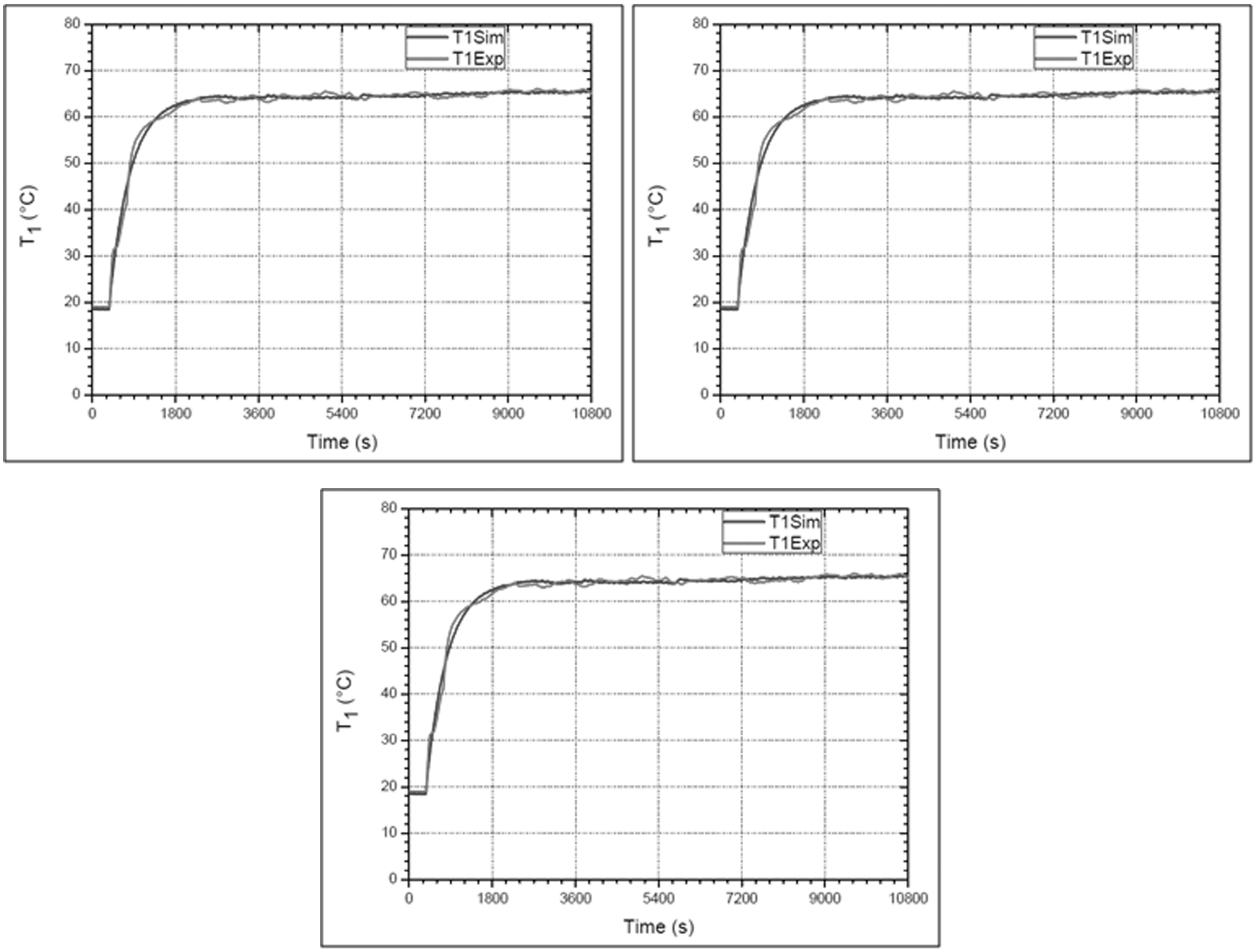

Figure 6: Comparison between simulated and measured temperatures T_1, T_{12} and T_{13}

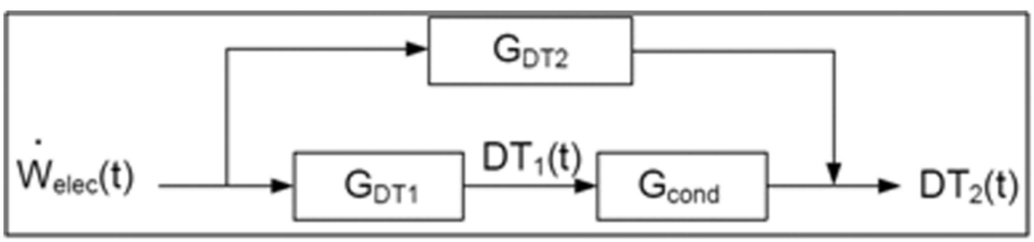

Figure 7: Diagram of the condenser model

The parameters of the obtained transfer functions are presented in Table. 2

Table 2
Model parameters and performance indicators for the condenser.

	K_p	T_p	T_d	*Fit (%)*
DT_1	0.72092	442.1	356.87	91
DT_2	0.49388	1216.9	607.47	89

$$G_{Cond} = \frac{G_{DT2}}{G_{DT1}} = 0.4059 \frac{1+442.1s}{1+250.09s} e^{-121.16s} \quad \text{(e)}$$

Figure 8 presents the Simulink model of the condenser.

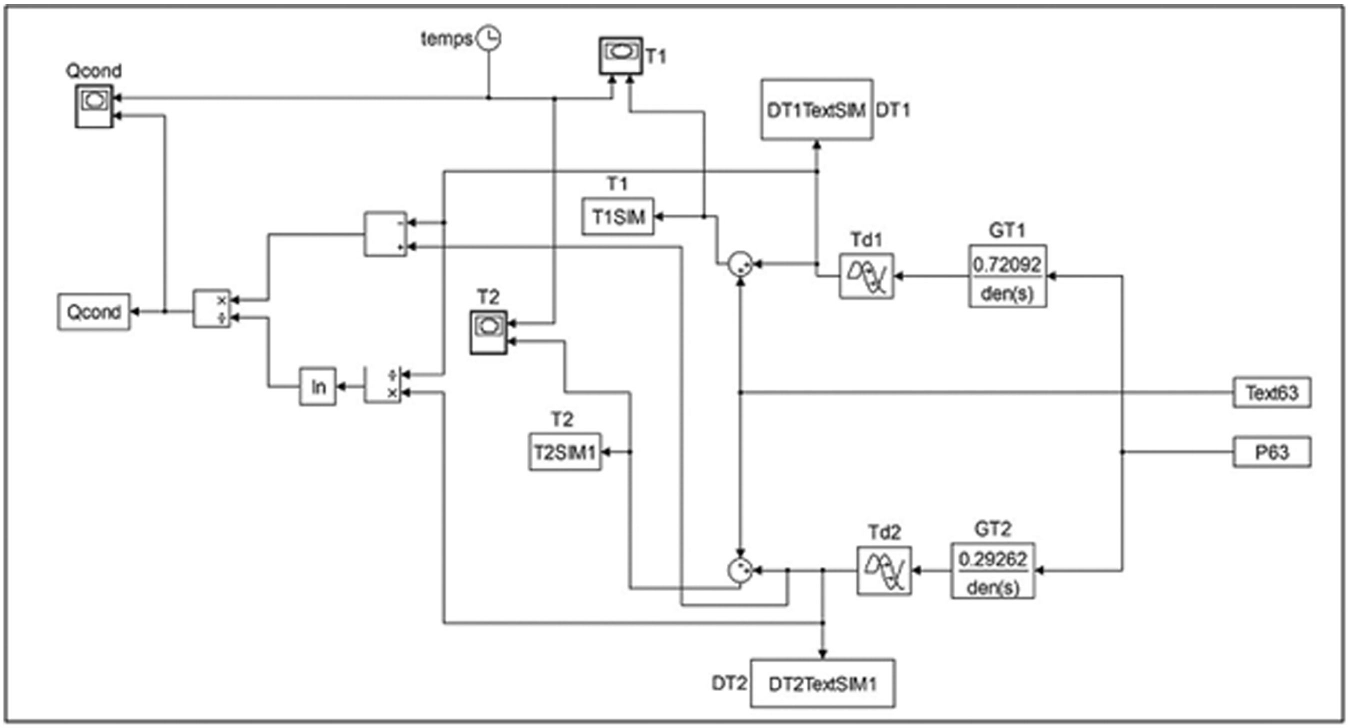

Figure 8: Simulink model of the condenser

The comparison between the model prediction results and experimental measurements are presented in Figure 9.

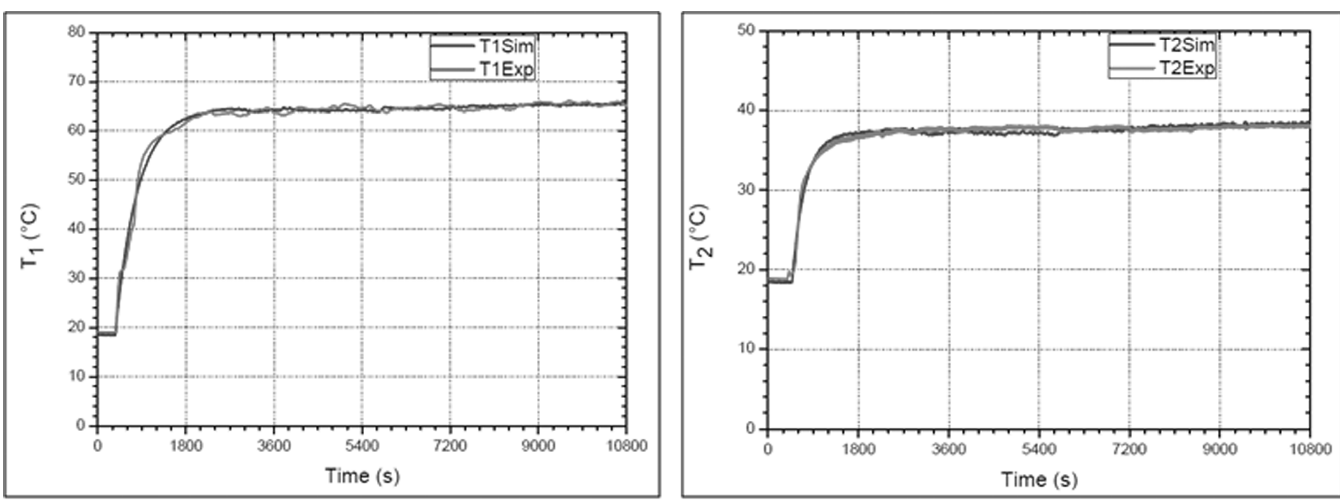

Figure 9: Comparison between simulated and measured temperatures T_1 and T_2

4.3. Evaporator

The mixture (at T_4), of liquid refrigerant arriving from the condenser through the GHX and the fluid rich in hydrogen leaving the absorber and the GHX, vaporizes on exchanging the cooling capacity with the inside of the refrigerator. The fluid leaves the evaporator at temperature T_7.

The modeling of the evaporator is to determine the relationship between the temperatures of the input and output streams (T_4 and T_7). The diagram of the model is shown in figure 10.

Figure 10: Diagram of the evaporator model

The parameters of the obtained transfer functions are presented in Table. 3

Table 3
Model parameters and performance indicators for the evaporator

	K_p	T_p	T_d	*Fit (%)*
DT_4	0.52048	221.41	389.1	78
DT_7	0.3997	1084.2	951.8	92

The evaporator transfer function:

$$G_{Evap} = \frac{G_{DT7}}{G_{DT4}} = 0.7679\frac{1+221.41s}{1+1084.2s}e^{-562.7s} \tag{f}$$

A Simulink model of the evaporator was developed. The comparison between the simulation results and experimental measurements are presented in Figure 11.

4.4. Absorber

In the absorber the weak solution, at the temperature T_{12}, dissolved the refrigerant contained in the gas mixture leaving the evaporator and reaching at the temperature T_9. The strong solution obtained at the temperature T_{13} goes to the generator and the gas mixture rich in hydrogen is fed to the evaporator at the temperature T_5. Figure 12 shows the diagram model of the absorber.

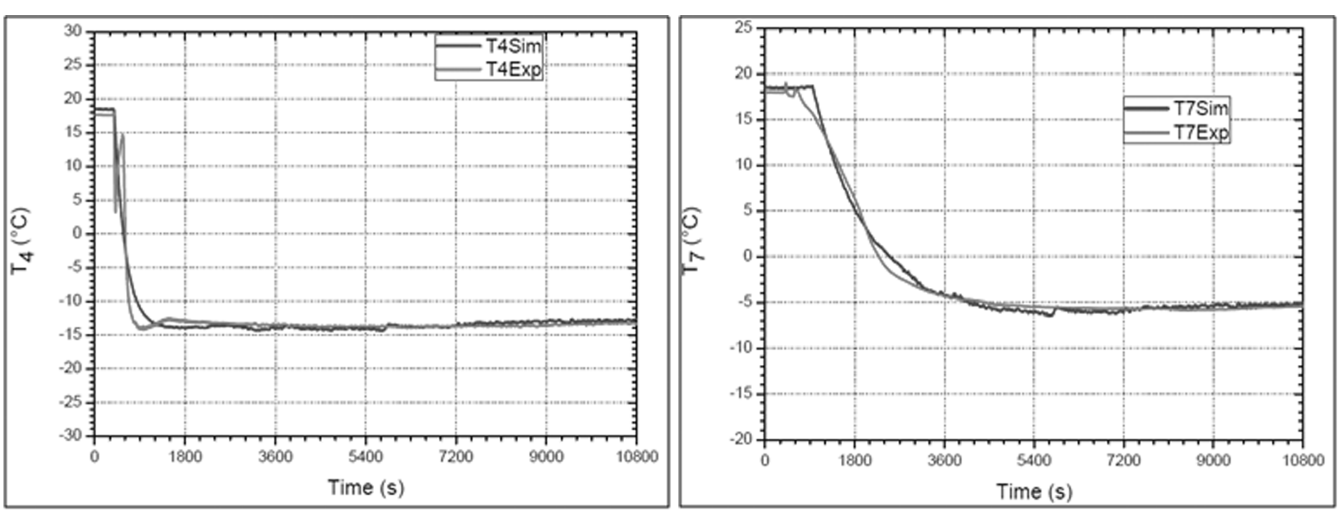

Figure 11: Comparison between simulated and measured temperatures T_4 and T_7

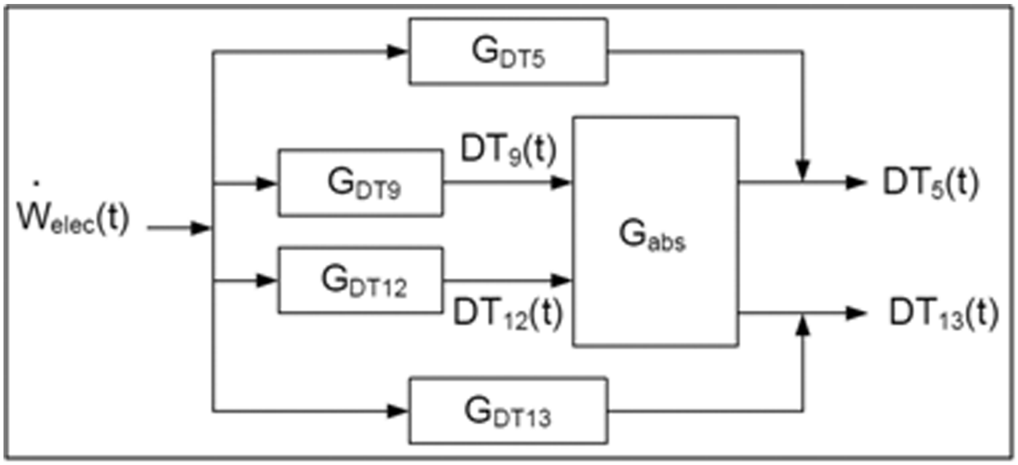

Figure 12. Diagram of the absorber model

The parameters of the obtained transfer functions are presented in Table. 4

Table 4
Model parameters and performance indicators for the absorber.

	K_p	T_p	T_d	*Fit (%)*
DT_9	0.37524	610.43	773.63	92
DT_5	0.40666	8867.55	699.26	95
DT_{12}	0.49388	1216.9	607.47	95
DT_{13}	0.50914	1139.7	909.88	94

A Simulink model of the absorber was developed. Figure 13 shows the comparison between the model prediction results and experimental measurements.

5. CONCLUSIONS

A commercial diffusion absorption refrigerator was experimentally tested for a 63W heat supplied. The input-output temperatures of every component- as well as of the cabinet and ambient are continuously measured and stored in a PC via a data acquisition system. The obtained experimental results are used to model the dynamic response for each components of the DAR. Developed models prediction results were

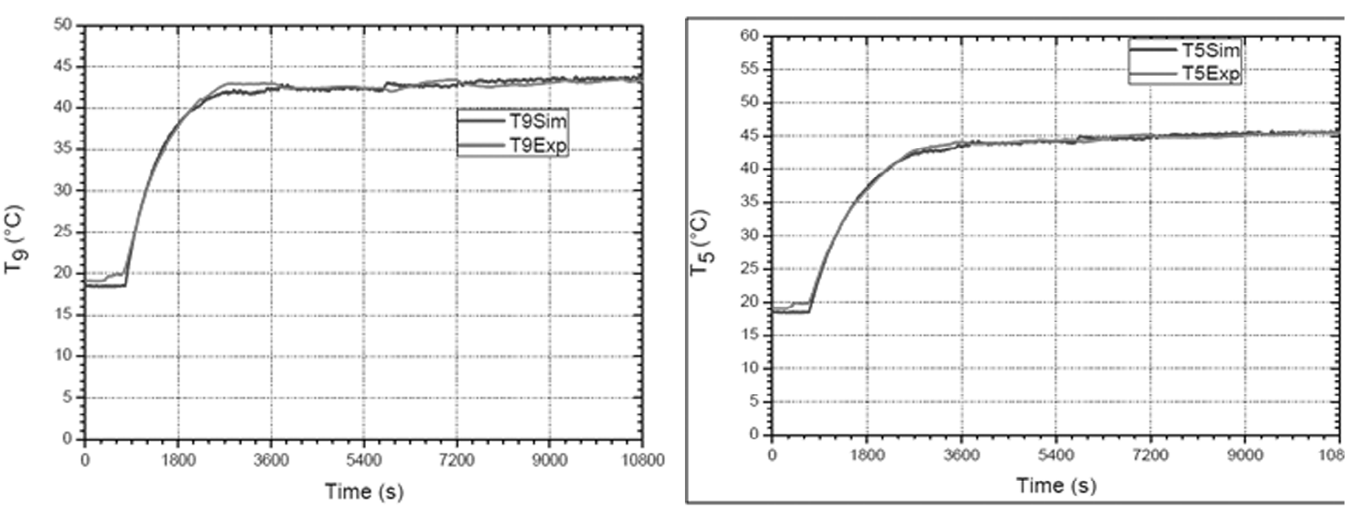

Figure 13: Comparison between simulated and measured temperatures T_9 and T_5

validated with experimental data. The proposed models could be very useful to predict the functioning of the commercial diffusion-absorption refrigerator under dynamic regime.

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