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THERMAL SIMULATION OF REFRIGERATION SYSTEMS

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The aim of this research is to develop a thermal simulation model that can be used to investigate the thermal parameters of the different regulation (ON-OFF and PID) air-conditioning system used to cool the refrigeration chambers. Due to incomplete data supplied by a manufacturer, the PID controller of a DC refrigerator had been optimized, in a previous phase of this research project, by setting the appropriate proportional, integrating and differential parameter values to ensure energy-efficient operation. Development of simulation model is carried out by MatLab simulation tool to estimate the energy consumption of refrigeration systems used in commercial cold stores considering the type of compressor, expansion valve and controller technic that are used on the market. Comparing the simulation results with the experimental results performed in the previous investigation in the topic good agreement can be seen between them.

Keywords: *thermal simulation, refrigeration system, energy consumption, ON-OFF Control, PID control*

1. Introduction

In a previous research project, the energy consumption of a newly developed DC inverter refrigerator (used more and more frequently in the commercial sector) was optimized, which included a speed-controlled compressor, an electronic expansion valve and the PID controller [1]. In order to achieve the research goals, an experimental measuring station was built in the showroom of the domestic market leader company selling refrigeration systems [3-8]. The main part of the measuring system was a cooling chamber that contained two identical evaporators; one was powered by the DC-inverter refrigerator, and the other was supplied with refrigeration energy by a cooling unit widely used in the domestic market, which is operated by a conventional piston compressor, a mechanical expansion valve and an ON-OFF (two-position) control technology. Due to the incomplete data supplied by the manufacturer, the PID controller of the DC cooling unit had to be optimized by setting the appropriate proportional, integral and derivative tags to ensure energy-efficient operation [9-14].

As a continuation of the research, the aim is to develop a thermal simulation model that can be used to examine the thermal parameters of the air conditioning systems (with ON-OFF and PID control) used to cool the cooling chambers. Another aim is to validate the developed simulation model with the measured results obtained during the previous phase of the research work [1]. Richárd Simon MSc. student assisted in the research project and resulted an excellent work on Conference of Scientific Students' Associations [2].

2. Structure of the simulation model

A thermal simulation model was developed in an earlier stage of the research work to examine the energetic characteristics of the refrigeration systems [1] used during the experiments in greater detail. If the results obtained from the developed simulation model approximate the experimental results with adequate accuracy, then by changing the characteristic parameters of the system, further conclusions can be drawn regarding its operation and avoid the installation of a new experimental measuring unit or the reconstruction of the existing one, which would require high investment costs. The current stage of the research first comprised the simulation of the effect of the various control systems (PID and ON-OFF) on the energy consumption of the cooling unit.

MatLab R2016a and its Simulink module with SimScape elements were used to create the simulation. The generalized system architecture is shown in Figure 1.

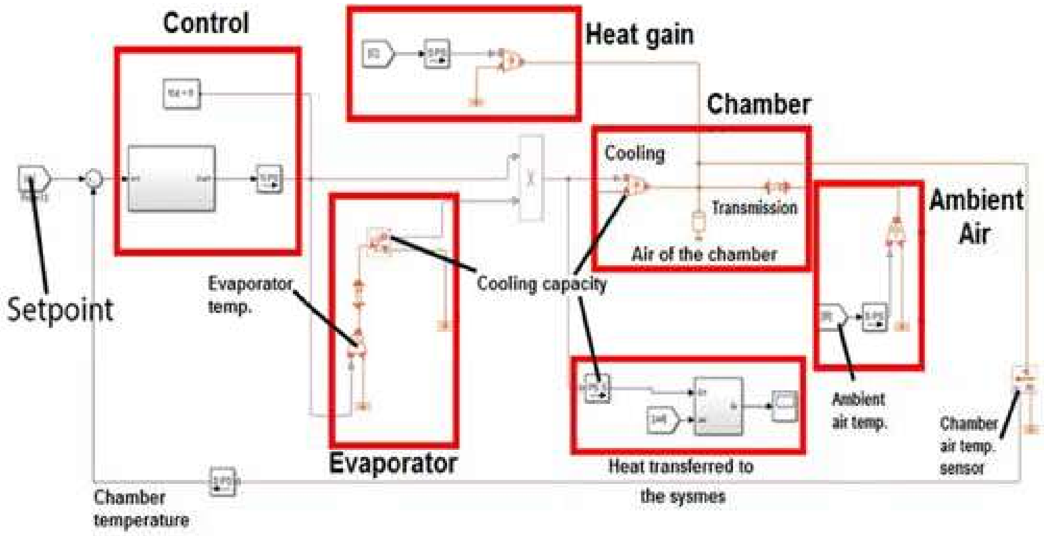

Fig.1. Schematic of the Simulink model of the refrigeration system

Since at this stage of the research work the aim is to compare the ON-OFF and PID controlled systems, only the control method will differ between the simulation models presented later. The diagram shows that the system compares the setpoint (the set temperature to be maintained) with the actual air temperature measured in the chamber and controls the refrigeration power accordingly.

So-called SimScape elements can be used in the Matlab Simulink module, including Thermal Elements which are perfectly suitable for the energetic modeling of the refrigeration systems examined in the research project. The characteristic values of each item used had to be specified [e.g. the mass and heat capacity of the material (air) in the chamber; evaporator heat transfer coefficient, etc.].

For the development of the simulation model, the technical data (heat transfer surface, heat transfer coefficient) of the evaporator and the chamber were taken into account with values provided by the the manufacturer, and the calculations—similarly to the experiments—include an 500 [W] of internal heat load ("extra heat load").

A thermal model was created during the development of the simulation model; it does no comprise mechanical elements, that is, the refrigeration cycle is not modelled, but it is among the future goals as a continuation of the research.

Structure of the simulation model for the cooling unit with ON-OFF control

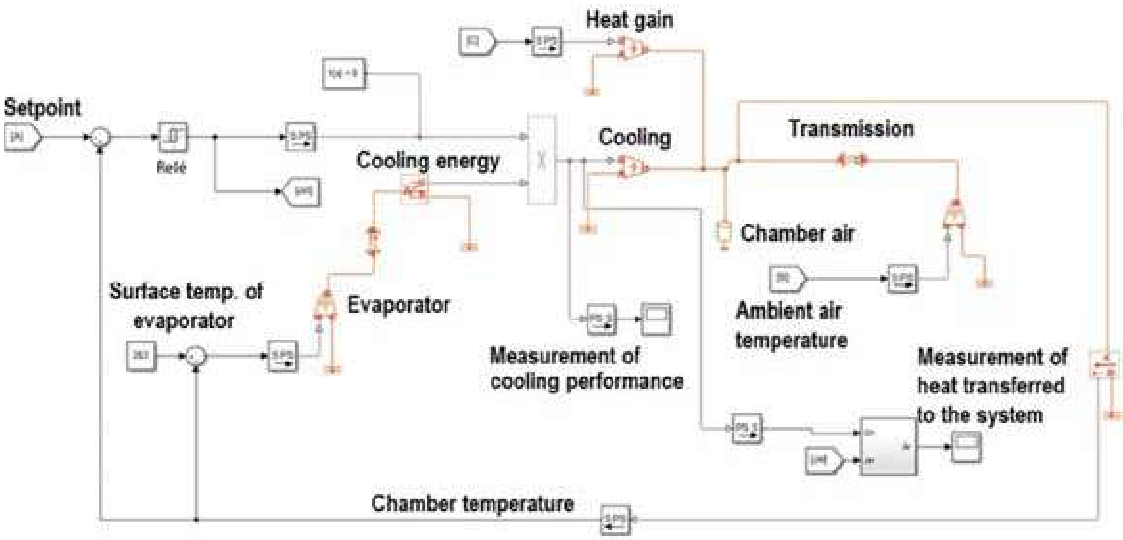

Fig. 2. Overview of the simulation model for the system with ON-OFF control

Structure of the simulation model for the cooling unit with PID control

Figure 3 shows the structure of the simulation model for the refrigeration systems with PID control.

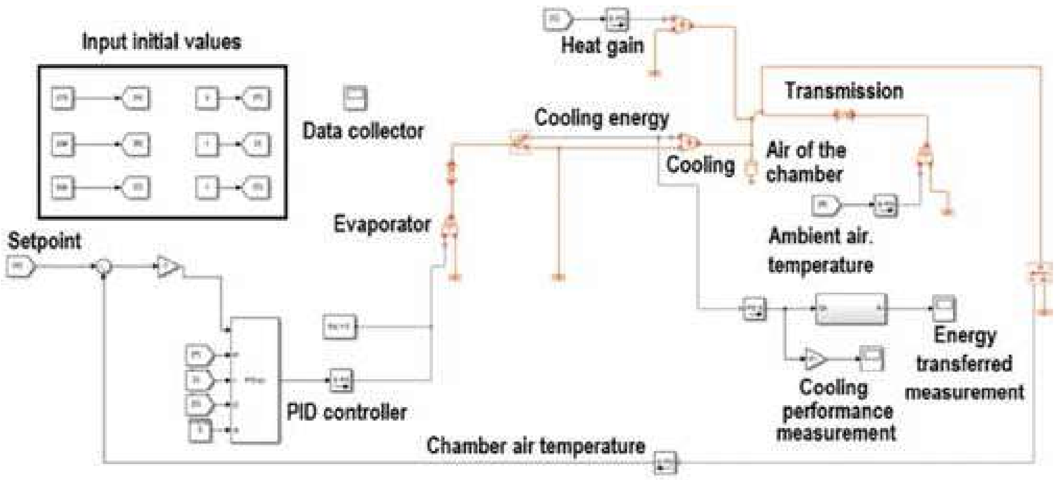

Fig. 3. Overview of the simulation model for the system with PID control

3. Comparison of the measured and simulated results, simulation model analysis

PID settings has to be identical to ensure that the simulation results are comparable to the measured values obtained during the experiments. Accordingly, the mentioned overdamped system was compared with the third measurement sequence [1] (in a non-transient state).

Figure 4 shows the system with ON-OFF control, and Figure 5 shows the system with ON-OFF control.

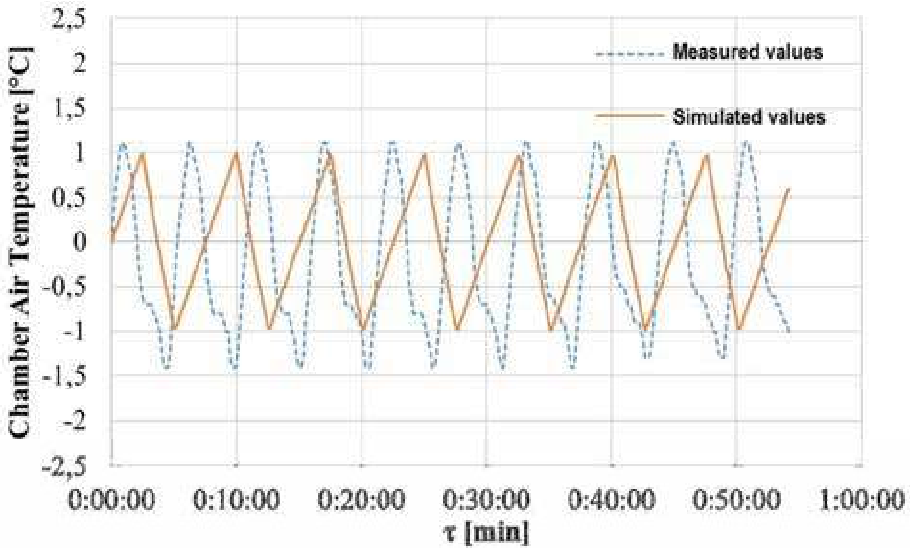

Fig. 4. Comparison of the simulated and measured results for the unit with ON-OFF control

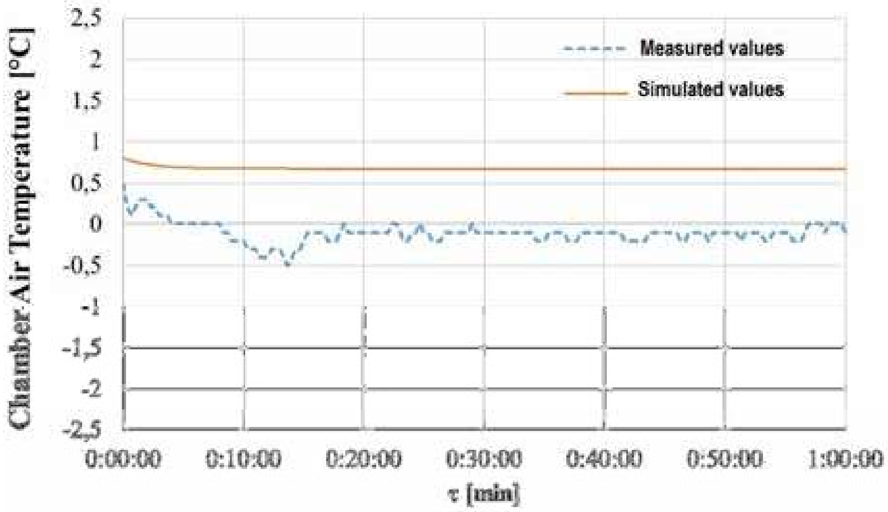

Fig. 5. Comparison of the simulated and measured results for the unit with PID control

The only difference is the difference between the stable values. This might be attributed to the position and inertia of the thermometer mentioned at the On/Off unit. The majority of the air in the chamber has already cooled down by the time the thermometer assumes the corresponding temperature. Another reason might be that the simulation model includes an ideal, continuously operating PID controller in contrast to the discrete (indicating values at certain time intervals) controller used during the measurement. In addition, the exact structure of the real controller and its error are unknown and this can also lead to a difference.

Other possible factors resulting in a difference between the measured and simulated results:

- the thermal simulation model does not contain the other elements of the refrigeration circuit (compressor, condenser, expansion valve and pipelines),
- the PID directly controls the evaporator due to the omission of the refrigeration cycle, • the location, resolution and measurement uncertainty of the measuring devices can also cause deviation from the ideal values of the simulation,
- for the model, the nominal values provided by the manufacturer were used, which can be different from reality.

If we accept the above, it can be stated that the developed thermal model represents the operation and thermal dynamical behavior of the system with near adequate accuracy.

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