12th International Symposium on Exploitation of Renewable Energy Sources and Efficiency

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EXPRES 2020

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CIP - Каталогизација у публикацији , Библиотека Матице српске, Нови Сад ,
INTERNATIONAL Symposium on Exploitation of Renewable Energy Sources and Efficiency (18;2020;Subotica)
Proceedings [Elektronski izvori] / 12th International Symposium on Exploitation of Renewable Energy Sources and Efficiency, Subotica, April 17-19, 2020 ; [proceedings editor József Nyers]. - Subotica : Inženjersko-tehničko udruženje vojvođanskih Mađara, 2020. - 1 elektronski optički disk (CD-ROM) ; 12 cm
Tekst štampan dvostubačno. - Tiraž 50. - Bibliografija uz svaki rad.

ISBN-978-86-919769-2-7

а) Енергија - Обновљиви извори – Зборници
COBISS.SR-ID

http://Expres 2020 ISBN 978-86-919769-2-7

SIMULATION MODEL DEVELOPMENT FOR ENERGETIC INVESTIGATION OF REFRIGERATION SYSTEMS

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Abstract - The aim of this research project is to investigate the energetic properties of PID and ON-OFF controlled refrigerant systems, as well as the effect of the product placed in the cooling chamber on the air temperature of the chamber and the cooling process of the product. To achieve this, a dynamic simulation model was developed, which was validated by using the measured energy consumption data obtained by experimental tests given from the previous phase of this research work. The developed simulation model enables the investigation of the thermal properties and energy consumption of the designed refrigeration chamber by building service and thermal engineers. With the help of the developed simulation model the transient effect of the controlled cooling system on the speed of the required cooling process due to the loading of the goods can be investigated, which can also influence the quality of the stored goods.

Keywords: *Refrigeration systems, Energy consumption; Simulation model development, Model validation*

1. Introduction

The type of the compressor, expansion valve, control system and refrigerant medium together has significant effects on the energy consumption of the refrigeration systems [1-5]. The most existing refrigeration systems worldwide are mostly equipped only with traditional two-position (on/off) temperature controller systems [6-9]. This simple controller has the output from the device is either on or off, the variable is changed between two values. Essentially, the on-off controller in the refrigerator compares the real inner temperature with the set temperature and feeds this error signal to the control input of the switch block of the controller. A proportional-integral-derivative controller (PID controller) is more appropriate to control the inner temperature of the refrigeration system and thus gives much higher performance for the response [10-12]. The PID controllers realize rapid and precise controlling. This is the reason why PID control is widely spread nowadays [13-19].

In a previous phase of this research project, the energy consumption of a newly developed DC inverter refrigerator was optimized, which included a speed-controlled compressor, an electronic expansion valve and the PID controller [20]. In order to achieve the goals, an experimental measuring station was built in the showroom of the domestic market leader company selling refrigeration systems. 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 [21].

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. As a continuation of the research, the aim is to develop a simulation model to examine the energy consumption of an air-conditioning systems used in cooling chambers, which takes into account the types of compressors, feeder and control units used commonly in practice, and to validate the simulation model with the measurement results obtained during the previous phase of the research work [22].

2. Development of the refrigeration cycle simulation model

Findings of research works performed in the past in the area show that the results of the simulation method can be further refined by considering the refrigerant. To do this, the whole refrigeration cycle must be modeled since the refrigerant circulates through this. From our point of view the useful phenomenon is the heat drain from the chamber, and it is a result of this cycle. The Matlab Simulink module makes it possible to model this as well because it includes a toolkit for biphasic systems. Since the refrigerant in the system is either gas or liquid, it can be treated as a biphasic substance. The model thus constructed can be seen in Figure 1.

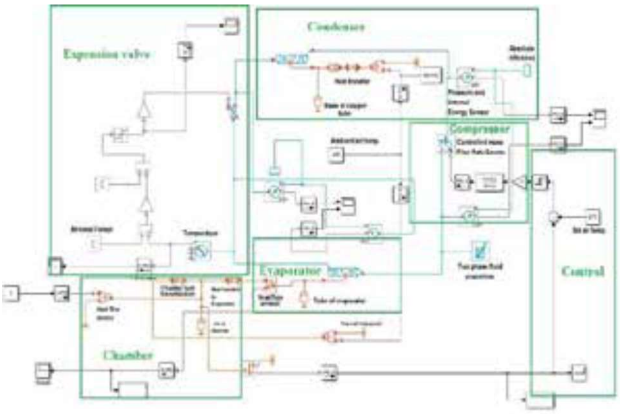

Figure 1 Schematic diagram of the refrigeration cycle simulation model

Figure 1 shows that the model has become significantly more complex compared to the previously developed thermal model. The blue parts are elements of the biphasic material and the red units are the thermal elements (an improved version of the previous model).

- Controllable mass flow: this is essentially the compressor, which provides the mass flow and pressure increase corresponding to the control.
- Pipelines with heat loss: for example the condenser and the evaporator. Depending on the geometry of the pipe and the material passing through it, the model calculates the amount of heat the pipe section can dissipate.
- Throttle: equivalent of the expansion valve. The extent of the throttle can be adjusted.
- Biphasic substance properties: this element makes it possible to connect the biphasic substance to the model by defining it.

The major disadvantage of the model is that a lot of data must be provided which were not necessary to specify in the cases that have been investigated so far; all of them is related to the refrigeration cycle. These data are summarized in Table 1.

The number of data required for the biphasic substance is high. In order to obtain a realistic behavior for the liquid in the 0–3 [bar] pressure range, the pressure has to be divided into 60 parts. Each such part has 25 values per quantity. This means that the number of ordered pieces of data for a phase is 10500. Therefore, 21000 pieces of data are needed to define the entire biphasic substance, and the data in Table 1 are needed in addition for the operation of the system. The additional unknown parameters were determined by estimation.

Table 1. Parameters taken into consideration for the refrigeration cycle model

Part	Required data
Condenser and evaporator	Pipe length
	Diameter
	Cross section
	Density
	Specific heat of its material
	Density of its material
	Resistance
	Gas proportion of the medium passing through
	Initial pressure of the medium passing through
Expansion valve	Minimum cross section
	Maximum cross section
	Minimum temperature
	Maximum temperature
Compressor	Transferred mass flow
Biphasic substance	Pressure vector
	Minimum specific internal energy
	Maximum specific internal energy
	For liquid: Normalized internal energy vector and as its function the
	specific volume
	specific entropy
	temperature
	kinematic viscosity
	thermal conductivity
	Prandtl number
	internal energy vector of saturated liquid
	The above for gaseous state

Figure 2 shows the progression of the chamber temperature for the on/off controlled case.

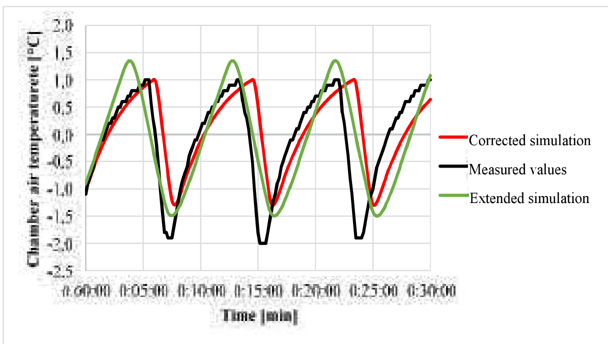

Figure 2 The change of chamber temperature over time based on measured, corrected simulation and extended simulation calculations in case of refrigeration systems with on-off control

By way of simulation, during the research, the effect the fresh goods stored in the chamber have on the air temperature of the chamber, the refrigeration power and the energy consumption was examined. 5 [kg] goods near the specific heat of water with an initial temperature of 27 [°C] were placed in the chamber. First, it was necessary to determine the heat transfer coefficient between the product and the chamber air. Based on the convection operation of the evaporator fan, it is specified as 15W/m2K. The test is carried out in a non-transient state, and the product appears in the chamber in the 40th minute. Figure 4 shows the Simulink mathematical representation used for this. A shortcoming of the model that the goods are placed instantly, so the door opening is not yet modeled; this is among the goals during the future continuation of the project.

3. Results

The results are summarized in Figures 3–5. Figure 3 shows the change in the temperature of the ON / OFF controlled chamber and the goods over time; Figure 4 shows the same for PID control (the upper limit of the X axis was restricted for better clarity). Figure 5 shows the change in the energy consumption of the two refrigeration systems using different control over time following the placement of goods.

Figures 3-5 clearly show the effect of the placed product. In the on/off case, the product can quickly heat up the air due to the high temperature difference present between the product and the chamber air when the goods are placed.

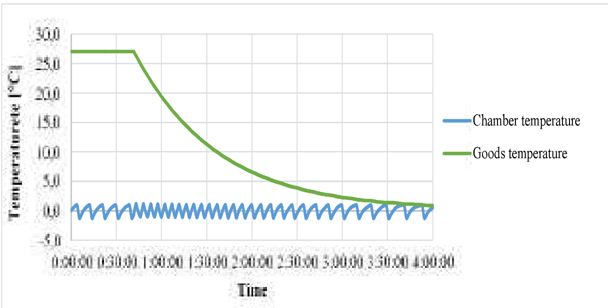

Figure 3 The change in the temperature of the on/off controlled chamber and the goods over time

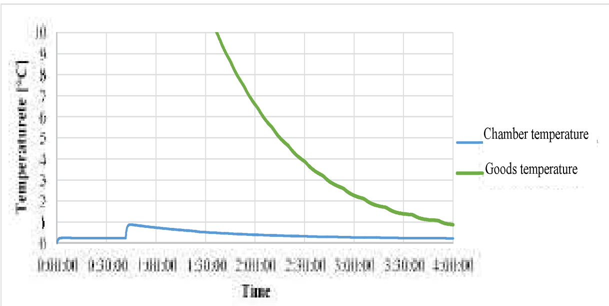

Figure 4 The change in the temperature of the PID controlled chamber and the goods over time

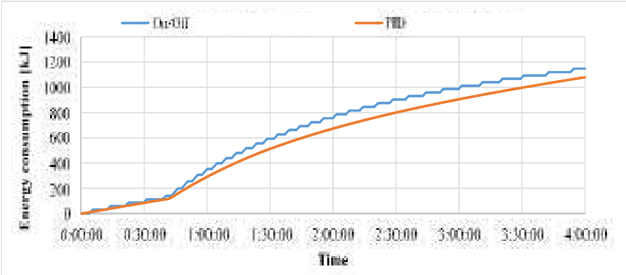

Figure 5 The change in the energy consumption of the PID and on/off controlled refrigeration systems over time following the placement of the goods

Since the cooling unit performs the control based on the temperature of the chamber air, it is deactivated at a temperature of -1 [°C] just the same, and it can cool this almost in the same way as before. This increases the number of the switching operations which can damage the compressor, and thus shorten its life span. In addition, the effect of the starting current occurs more frequently, resulting in a difference compared to the energy consumption of the PID controlled refrigeration system. This points out that the difference between the two control methods becomes more significant with the increase of the goods placement frequency. In the PID controlled scenario, the conclusion is that the system can flexibly follow the refrigeration demand of the placed product and is able to provide the required refrigeration power efficiently if the control is set up properly. After the product has been cooled appropriately, only the transmission heat loss has to be covered by the machine; that is, it only has to ensure the maintenance of the temperature.

Acknowledgement

This research project was financially supported by the National Research, Development and Innovation Office from NRDI Fund [grant number: NKFIH PD_18 127907] and János Bolyai Research Scholarship of the Hungarian Academy of Sciences, Budapest, Hungary. Moreover the research reported in this paper was supported by the Higher Education Excellence Program of the Ministry of Human Capacities in the frame of Artificial Intelligence research area of Budapest University of Technology and Economics (BME FIKP-MI).

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