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EXPERIMENTAL TESTS ON HEAT TRANSFER IN COIL CONDENSERS DESIGNED FOR BUILT-IN REFRIGERATORS

ANKASTRE BUZDOLAPLARI İÇİN TASARLANAN SERPANTİN YOĞUŞTURUCULARIN ISI TRANSFERİ ÜZERİNE DENEYSEL TESTLERİ

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Abstract

A vapor compression refrigeration cycle is a closed cycle consisting of a compressor, a condenser, an expansion valve and an evaporator. The performance of the cooling system is significantly dependent on the condenser. The aim of this study is to conduct heat transfer tests on the compact condensers of built-in refrigerators and to propose improvement suggestions according to the test results. In the introduction section, information is given about the type of condenser used in built-in refrigerators and the parameters affecting the heat transfer. In the material and methods section, the selected coil type condenser and the constraints on the component where it is mounted are explained. Explanatory information about the experimental setup to be used can also be found in this section. In the results section, the results of the experiments on the coil condenser are given. The test results in the discussion section were examined and suggestions were made to increase the performance of the condenser on the refrigerator. The results show that the heat transfer capacity, which is an important parameter determining the condenser performance, and the pulldown temperature are directly related to the condenser surface. It can also be concluded that even if the condenser thermal capacity is sufficient, the pulldown temperature should also be taken into account. Although the thermal capacity of the coil condenser meets the requirements, it is observed that the pulldown temperature is not at the desired values.

Keywords: Coil Condenser, Cooling System, Heat Transfer, Optimization, R134a, Refrigerators

Özet

Bir buhar sıkıştırmalı soğutma çevrimi, bir kompresör, bir yoğuşturucu, bir genleşme valfi ve bir buharlaştırıcıdan oluşan kapalı bir çevrimdir. Soğutma sisteminin performansı önemli ölçüde yoğuşturucuya bağlıdır. Bu çalışmanın amacı, ankastre buzdolaplarının kompakt yoğuşturucusunun üzerinde ısı transferi testleri yapmak ve test sonuçlarına göre iyileştirme önerileri sunmaktır. Giriş bölümünde ankastre buzdolaplarında kullanılan yoğuşturucu tipi ve ısı transferini etkileyen parametreler hakkında bilgi verilmiştir. Malzeme ve yöntemler bölümünde seçilen serpantin tipi yoğuşturucu ve monte edildiği yer üzerindeki kısıtlamalar anlatılmaktadır. Kullanılacak deney düzeneği hakkında açıklayıcı bilgiler de bu bölümde bulunabilir. Sonuçlar bölümünde ise serpantin kondenser üzerinde yapılan deneylerin sonuçları verilmiştir. Tartışma bölümündeki test sonuçları incelenmiş ve yoğuşturucunun buzdolabındaki performansının artırılmasına yönelik önerilerde bulunulmuştur. Sonuçlar, yoğuşturucu performansını belirleyen önemli bir parametre olan ısı transfer kapasitesinin ve aşağı çekme sıcaklığının yoğuşturucu yüzeyi ile doğrudan ilişkili olduğunu göstermektedir. Ayrıca, yoğuşturucu ısıl kapasitesi yeterli olsa bile, aşağı çekme sıcaklığının da dikkate alınması gerektiği sonucuna varılabilir. Serpantin yoğuşturucunun ısıl kapasitesi gereksinimleri karşılamasına rağmen, aşağğı çekme sıcaklığının istenilen değerlerde olmadığı görülmektedir.

Anahtar Kelimeler: Serpantin Yoğuşturucu, Soğutma Sistemi, Isı Transferi, Optimizasyon, R134a, Buzdolapları

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1. INTRODUCTION

In built-in refrigerators, serviceability is of great importance in the design of components, especially as the volume is large and the device cannot be moved. In normal household type conventional refrigerators, static type wire-on-tube condensers located behind the appliance is used. In built-in refrigerators, on the other hand, compact condensers must be used instead of static wire-on-tube condensers in terms of ease of access to the condenser compartment, that is, its serviceability. A compact condenser is a type of heat exchanger which is specially designed to achieve a large heat transfer surface area per unit volume (Cengel & Gajar, 2020). Compact condensers are usually placed in the machine room part of the device, which is called the aggregate area.

As the surface areas of compact condensers are smaller than static type wire-on-tube condensers, static air contact is not sufficient for heat transfer. For this reason, to increase the heat transfer in compact condensers, the air is directed over the condenser with the help of a fan and thus heat transfer is increased. There are studies on the determination of the performance of an air-cooled condenser. The effect of various parameters on condenser performance was investigated in a study (He et al., 2013). As the aim of this study is to reveal the effect of condenser design on heat transfer, fan size and parameters will be out of the scope of this study. Figure 1 shows the condenser and fan located in a built-in refrigerator.

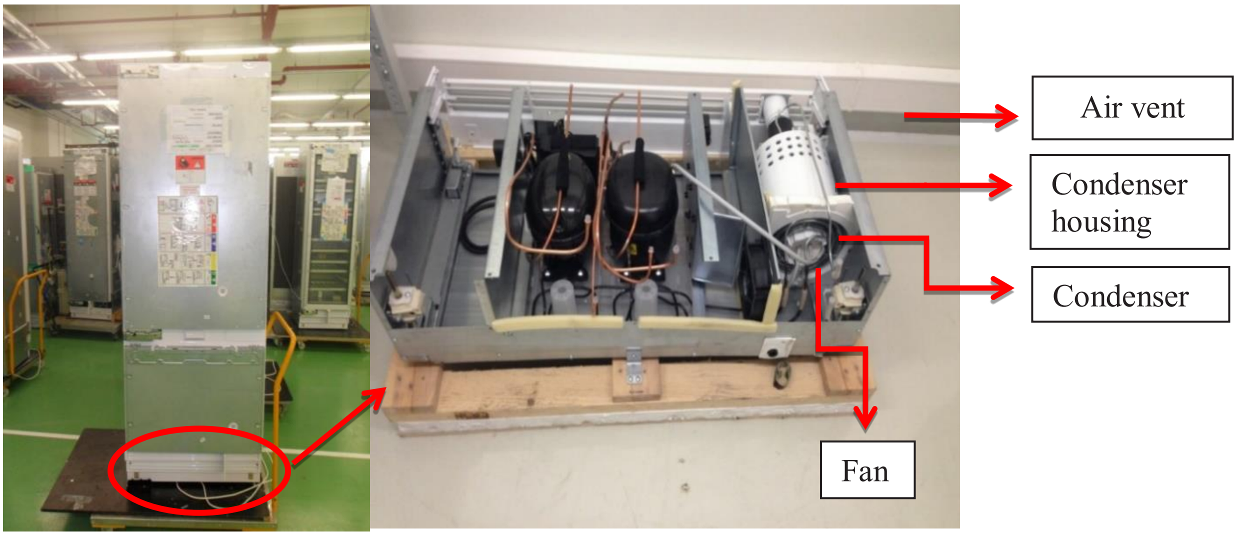


Figure 1: Compact condenser location in built-in refrigerators.

R134A refrigerant passes through the cooling system of the refrigerator. Heat is transferred to R134A inside the refrigerator compartments through the evaporator and later heat is transferred to the environment by the condensing process in the condenser.

There are two criteria to measure the suitability of condensers. The first of these is the heat transfer capacity of the condenser. Another criterion as important as heat transfer capacity is the saturation temperature of the refrigerant at the outlet of the compressor. The pressure corresponding to the saturation temperature is a factor that affects the operation of the compressor. The upper limit of the pulldown temperature value is determined by the compressor manufacturers by performing lifetime tests and it is requested not to exceed a certain temperature. For this reason, it is not enough if only the heat transfer capacity of the condenser meets the requirements. At the same time, the pulldown temperature must be below the limit value.

The aim of this study is to experimentally investigate the heat capacity and pulldown temperature of the condenser and to make suggestions for the designed condenser and test method according to the results.

2. MATERIALS AND METHODS

In the study, a built-in refrigerator called the bottom mount was used. The freezer section with drawers is located at the bottom and the fridge section is at the top. The built-in refrigerator can be seen in Figure 2.

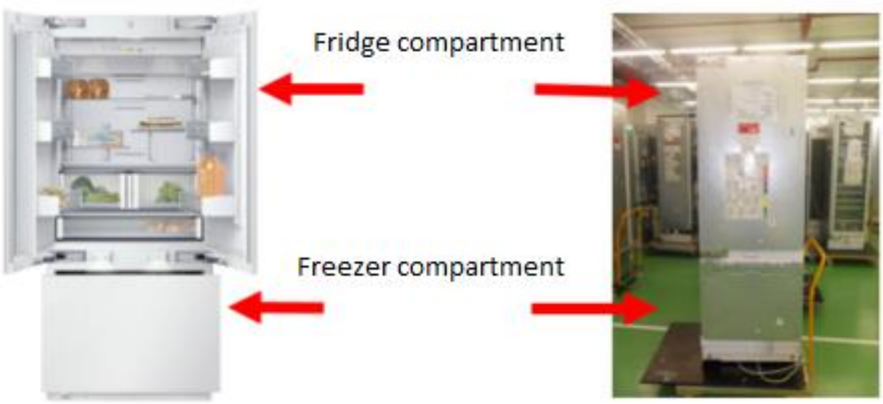


Figure 2: Bottom mount built-in refrigerator.

The condenser used in built-in refrigerator is coil type. The structure of the condenser made of aluminum pipes can be seen in Figure 3. It is placed in a housing so that air flow can be provided into the condenser. The condenser has two refrigerant inlets and outlets. The refrigerants of the refrigerator and freezer compartments pass through these inlets and outlets separately. The fluids of these separate compartments do not mix with each other. The physical properties and dimensions of the coil condenser pipes are given in Table 1.

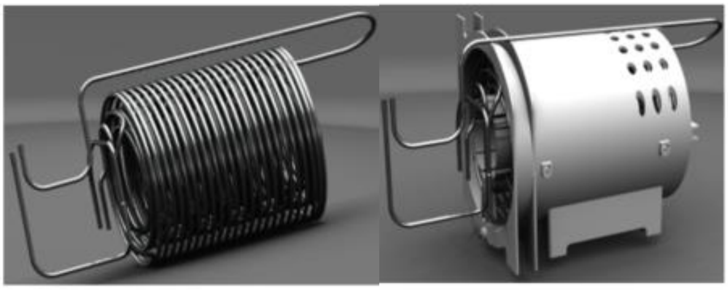
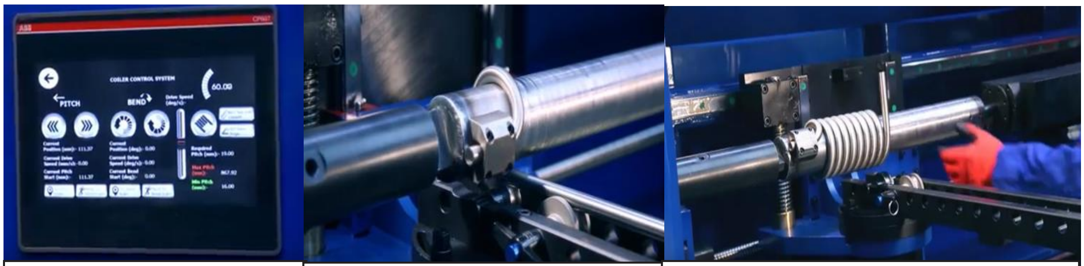


Figure 3: Compact coil condenser and housing (Tezcan, 2018).

Table 1: Physical properties and dimensions of coil condenser pipes.

Material	Aluminum
Outer diameter (mm)	4.76
Thickness (mm)	0.7
Thermal conductivity λ (W/mK)	200
Fridge compartment pipe length (mm)	14088
Freezer compartment pipe length (mm)	12503

As a basic principle, the coil condenser is produced by displacing a rotating shaft forward by means of a worm gear screw and taking shape with the effect of this rotation and progression of the pipe on it. The process is shown in Figure 4.



Adjusting the feed rate, pipe length and coil pitch of the twisting machine	Placing the straight pipe on the spindle and starting the bending process	Completion of the twisting process, removing the spindle and condenser

Figure 4: Coil condenser production method.

This production methodology and condenser types used in built-in appliances are well-known technology. There are different patent applications for the condenser type obtained by horizontally forward translation of the pipe in a helical rectangular or circular form (Heisen, 1998), (Arslankiray, 2008).

Two different test systems have been considered to evaluate the performance of the condenser. First study was performed on the performance of condenser on the refrigerator by getting the result for pulldown temperature. The second study was performed on single condensers to get heat capacity test results of them.

2.1. Pulldown Temperature Tests on The Refrigerator

The energy level measurement tests of the refrigerator are out of the scope of this study. However, when the condenser is mounted to the refrigerator, it can use the same test setup to measure the inlet and outlet temperatures. The test chambers shown in Figure 5 were used to determine the temperatures of critical points in the BM-type refrigerator. By placing the device to be measured in these test chambers, measurements can be made under previously set temperature and relative humidity conditions. The measurements made were collected at a service provider and data graphics are automatically gathered by means of user interaction graphics and results.

Figure 5: Refrigerator with temperature sensors connected in the test chamber.

PT100 thermocouples were used to measure the temperatures. Thermocouples were attached to the area where the temperature is measured with aluminum tape. The aluminum band provides a homogeneous temperature distribution on the thermocouple, helping to make the measurement sensitively. The application for installing thermocouples is shown in Figure 6.

Figure 6: Thermocouple mounted on the compressor outlet pipe.

2.2. Heat Capacity Measurement Test System

A test setup specially designed to measure the thermal capacity of the condenser was used. The condenser to be tested was placed in an air duct. Airflow was provided by an exhaust fan. The volumetric flow of the air was measured with a nozzle and a pressure transmitter. A flow regulator is used to achieve uniform flow in the air duct.

R134a gas was used as the refrigerant in the test setup. The inlet temperature of the tested condenser was controlled by changing the heater heating output or evaporator cooling output parameters in the heat exchanger. The temperature of the fluid exiting the condenser was lowered by the super cooling up to the set value. The mass flow rate of the fluid was measured with a flow meter placed after the super cooling. The flow rate changes according to the constant inlet and outlet temperatures of the condenser. The fluid flows from the super cooler to the evaporator. The refrigeration cycle is completed when the fluid leaving the evaporator goes into the compressor. The thermal capacity of the condenser with known temperature values and flow rate is calculated automatically by the system. Constant temperature values and test parameters for each compartment is given in Table 2.

Table 2: Condenser heat capacity measurement system test parameters.

Divison	Test chamber temperature (°C)	Super heating (°C)	Super cooling (°C)	Condensing temperature (°C)	Refrigerant
Freezer	22	5	7	46	R134a
Fridge	13	5	7	38	R134a

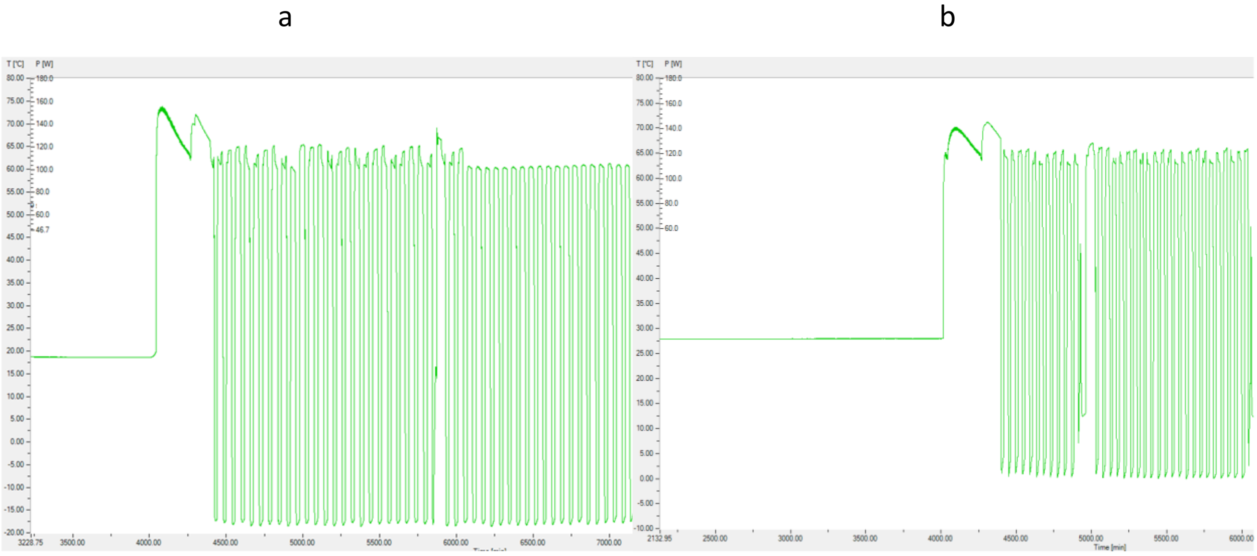

a

b

Figure 7: Condenser heat capacity measurement test system, a) control panel, b) air channel.

3. RESULTS AND DISCUSSION

Compressor outlet saturation temperatures of the freezer and refrigerator of refrigerant compartments are given in Figure 8 as a result of the tests performed to find the pulldown temperatures on the refrigerator. x axis on the figure refers time as second (s) as y axis shows temperature as °C. The comparative list of the results can be seen in Table 3.


a

b

Figure 8: Saturation temperatures of refrigerant at the compressor outlets for the freezer and refrigerator compartments, a) Freezer compartment compressor outlet, b) Fridge compartment compressor outlet.

Table 3: Compressor outlet saturation temperatures of the compartments according to the refrigerator operating status.

Operation mode	Maximum compressor outlet saturation temperature for freezer	Maximum compressor outlet saturation temperature for fridge	Operation mode
Start-up	73.8	71.2	Start-up
Cycle	69.1	67	Cycle

Results of condenser heat capacity determination tests are given in Table 4.

Table 4: Condenser heat capacity test results.

Division	Length (m)	Heat Transfer Capacity (W)	Refrigerant mass flow rate (kg/h)	Air mass flow rate (m^3/h)
Fridge	14.09	311.5	6.49	196.4
Freezer	12.5	249.7	4.97	185.2

The pulldown temperature should not exceed 70°C during start-up. According to the test results on the refrigerator, these temperature values during start-up are 71.2°C for the fridge compartment and 73.8°C for the freezer compartment. Likewise, after the device works in the cycling, this temperature value is 67 °C for the fridge compartment and 69.1 °C for the freezer compartment.

The saturation temperature of the fluid can be derived from the pressure-enthalpy (P-h) diagram. The pressure corresponding to the pulldown temperature values can be seen in Figure 9 and Figure 10.

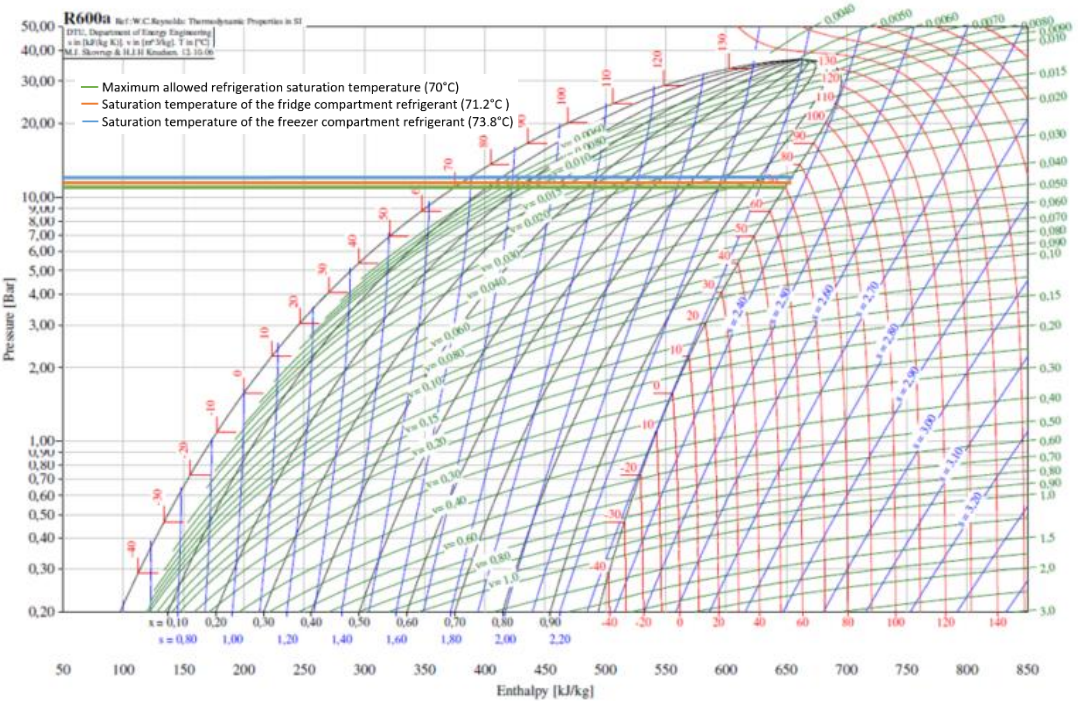


Figure 9: Saturation pressure of refrigerant in P-h diagram during refrigerator start-up.

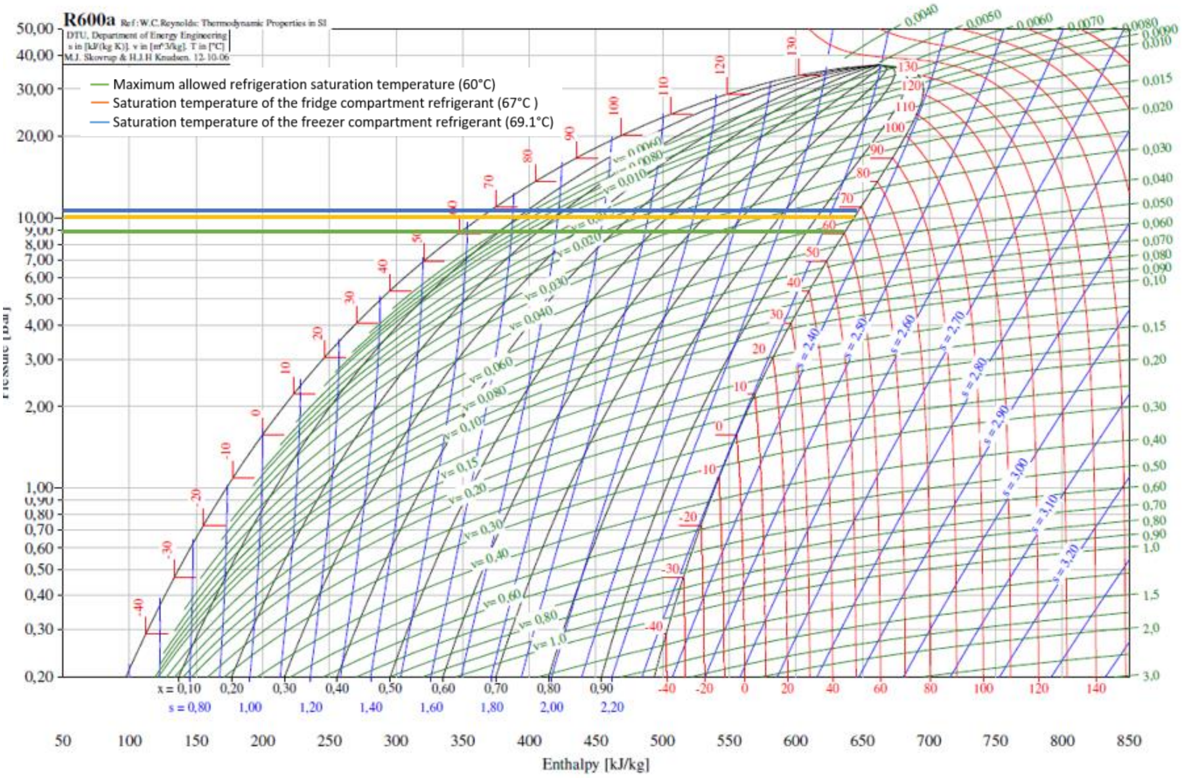


Figure 10: Saturation pressure of refrigerant in P-h diagram during refrigerator cycling.

As seen from the P-h diagram, during start-up of the refrigerator, the saturation pressure for the saturation temperature value of 70°C is 12 bar, and the saturation pressure corresponding to the maximum saturation temperature of 60°C in cycling is 9 bar. It should be noted that these pressure values are the maximum values allowed for the compressor in start-up and cycling operation. The refrigerant temperatures for both operating conditions are above the maximum allowable operating pressures for the compressor. The pressures corresponding to the saturation temperature during refrigerator start-up and cycling operating conditions are taken from the P-h diagrams presented above and shown in Table 5.

Table 5: Saturation pressures corresponding to saturation temperatures.

Refrigerator operation status	Division	Refrigerant saturation temperature (°C)	Refrigerant saturation pressure (bar)	Max. operation pressure (bar)
Start-up	Fridge	71.2	12.5	12
Start-up	Freezer	73.8	13	12
Cycling	Fridge	67	10	9
Cycling	Freezer	69.1	10.7	9

As seen from Table 5, refrigerant pressure is higher than the maximum allowable pressure of the compressor, which is one of the basic components of the cooling system. Operating pressure at these levels is not desirable. The pressures must be brought to the desired levels by considering the entire cooling system. Especially the condenser design is of great importance. It should be noted that not only the condenser design, but also other cooling system elements should be taken into consideration. However, as the aim of this study is to specify the optimum condenser design, the improvement suggestions will be limited to this component.

In order to reach the appropriate working pressure for the compressor, the heat transfer to the environment via the condenser should be increased. As seen from Table 4, the heat transfer capacities of the cooler and freezer compartments are 311.5 W and 249.7 W respectively. It is recommended to increase the heat transfer capacities of both compartments to reduce the saturation temperature at the compressor outlet and thus the saturation pressure. The changes that can be made on the condenser to increase the heat transfer can be listed as follows.

3.1. Changing the configuration of the tube coil

There are studies in the literature indicating that changing the coil configuration can significantly change the heat transfer capacity. By using the appropriate configuration, 7.85% increase in air volume and 5.29% increase in heat transfer can be achieved (Lee et al., 2010). The increase ratio is different according to different design configurations. Also according to an experimental and theoretical study on coolers with helical type tube condenser, it has been shown that the efficiency coefficient of the cooler increases with decreasing helix diameter in the geometric parameter range considered (Elsayed et al., 2012). Different designs in which complete geometrical restrictions allow should be considered and re-tested. But also it should be noted that, because of location restrictions of refrigerator aggregate area, design with different coil configuration is not so simple.

3.2. Increasing the heat transfer area by increasing the condenser tube length

Heat transfer capacity increase of the condenser can be achieved by a higher heat transfer area. The way of the increase of the heat transfer area is to increase pipe length. Increasing the length of the pipes of the existing condenser does not seem so possible due to the geometrical restrictions of the housing where the condenser is located in. Additionally, the effect of the length increase should be tested because of some possible negative effects on heat transfer. Heat transfer in standard type wire-finned tube condensers used in domestic refrigerators was investigated. It is determined that with an increase in the condenser length, there would be an increase in the temperature of the air surrounding the condenser which caused a decrease in the heat transfer coefficient (Hofmanas & Paukstaitis, 2012). Therefore, optimization of pipe length is important. For this reason, a different design may be preferred rather than the current design. It is thought that such a design may be possible, especially in compact wire-on-tube condenser types.

3.3. Using wire fins to further increase the heat transfer surface

The current condenser design does not allow the heat transfer surface to be increased with wire fins due to both geometrical restrictions and welding impossibility of the aluminum material. By switching the design to wire-on-tube type condenser mentioned in the previous solution, the heat transfer surface can be significantly increased. Researches show that fin number and height have an important effect on heat transfer (Honda & Wang, 2001).

4. CONCLUSION

The effects of the coil condenser designed for built-in refrigerators on the cooling system and especially on the compressor operation were studied in this study. The results show that although the currently designed coil condenser gives good results on the system in terms of cooling capacity, the pressure of the refrigerant at the compressor outlet is above the desired levels. In its current form, it is not possible to increase the heat transfer amount of this condenser type because of geometric concerns and it is not possible to add wire fins to increase the heat transfer rate. It is expected that the heat dissipation capacity of the tubular and wire condenser can be much higher due to both possibilities of increasing the length of the tube and attaching the wire fins.

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