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AN EXPERIMENTAL INVESTIGATION ON THE EFFECTS OF REFRIGERANT CIRCUITING ON FREEZER PERFORMANCE

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ABSTRACT
In this study, the influence of the refrigerant circuiting on the performance of the refrigerator has been investigated experimentally. Since energy consumption of refrigerator or freezer is directly related to the evaporator efficiency in the cooling system, the circuitry design needs to be modified to improve the system performance. Experiments showed that lowest energy consumption and best cooling performance are achieved by evaporator with the refrigerant circuiting of 2-1-6-5-4-3 which are the number of shelves. The result has been obtained under the thermal conditions as average temperature of package is -18.4ºC and highest package temperature is -16.5ºC.

INTRODUCTION

Rapid consumption of energy sources in the world brought the need for economic and efficient use of energy. Since energy consumption cannot be avoided because of the fact that it is an indicator of industrial production and improvements, and it provides life quality. Eventually, researches increased broadly and rapidly for improving efficiency of the energy consumption. Surveys showed that household appliances have the highest share in terms of energy consumption. Therefore, increasing the efficiency of the products such as refrigerators and freezers which consume electricity at houses during all the day gained importance.

Evaporator is a heat exchanger in which refrigerant boils while absorbing the heat inside the cabinet of a refrigerator. Liquid refrigerant with low pressure and low temperature comes from capillary tube enters the evaporator and absorbs high amount of heat then boils. On the other side of the evaporator the density of cooled air in the upper shelves of the refrigerator is higher than the density of the relatively hot air in the bottom shelves Since the air is dense and cooler, it flows down thorough the bottom of the cabinet while the hot air rises. As a result, an air circulation is provided by natural means in the cabinet of the refrigerator. Therefore any improvement on the refrigerant side is worth to be considered.

The flow circuitry of the refrigerator is determined by considering the creation of the homogeneous cooling effect inside the refrigerator. Since the flow circuitry supplies different temperatures at different locations, the flow arrangement is necessary with respect to prevent temperature oscillation that is effective on the cooling performance and the energy consumption. For this reason, optimum flow circuiting should be selected in order to provide optimum cooling performance and the lowest energy consumption.

NOMENCLATURE

T	[K]	Temperature
RT		Run Time (Ratio of compressor on time to cycle time)

Subscripts

eva	Evaporator
cond	Condenser

Domanski and Yashar [1] examined the application of ISHED (Intelligent System for Heat Exchanger Design) to optimizing refrigerant circuits in finned-tube condensers.. The module operated in a semi-Darwinian mode and seeks refrigerant circuitry designs that maximize the condenser capacity for specified operating conditions and condenser slab design constraints. Examples of optimization run for with six different refrigerants that are R600a, R134a, R290, R22, R410A and R32. Their results showed that high-pressure refrigerants benefited from more restrictive circuitry architectures than the low-pressure R600a and R134a. The ratio of condenser capacity for the best performer, R32, and the worst performer, R600a, was 1.18. The superior heat exchanger performance of high-pressure refrigerants renders the opportunity to mitigate their inherent theoretical COP disadvantage in the vapour compression cycle as compared to low-pressure fluids.

A new methodology for the simultaneous optimization of refrigerant circuiting in air-air refrigeration systems with plate-fin and tube heat exchangers proposed by Martínez et al.[2]. Their new methodology had proved to be more efficient than traditional methods. The method had applied, in conjunction with a full refrigeration system simulator for the optimization of a high performance commercial air conditioning unit, considering the use of heat exchangers with tubes of different diameters. Their results appeared that, a predicted COP enhancement between 5.5% and 8.3% for system with R-22, and 6% - 6.5% for R410A, was observed with the optimization method.

Liang et al., [3] analyzed the performances of evaporator coils with complex refrigerant circuitry using a distributed simulation model, which has three elements: branch, tube and control volume. The governing equations for a control volume were presented in the paper together with the computer simulation procedure for branches, tubes and control volumes of a coil. The model predictions on four test coils have been validated with experimental data collected under different airflow conditions using R134a as a refrigerant. They have studied the heat transfer and fluid flow characteristics of the coils using this model. Their study showed that while the thermal resistance of refrigerant side is comparable to that of airside, the coil comprehensive performance can be improved by changing the refrigerant mass velocity along the flow path. Compared with a common coil, using a complex refrigerant circuitry arrangement where the refrigerant circuits are properly branched or joined may reduce the heat transfer area by around 5% in coil design. They proposed a guideline for the refrigerant circuitry arrangements to improve the coil performance.

The effects of circuitry on the performance of air-cooled condensers investigated by Wang et al. [4]. They had provided in-depth experimental information related to the effect of circuitry in the air-cooled condensers. Their results showed that counter-cross flow gave better performance than other arrangements for 1-circuit arrangements. However, the reversed heat conduction from the inlet portion to the exit portion may offset the benefit of counter-cross arrangement.

As it is seen in the literature, the flow circuiting has not been investigated and interested deeply whereas the results of the flow circuiting determine the quality of the refrigeration process. In this study, the effects of the flow circuiting are investigated experimentally. As seen in Figure 1, Evaporators used in this study consist of tubes on sheet metals which enlarge heat transfer surfaces. Cooling is provided by natural convection.

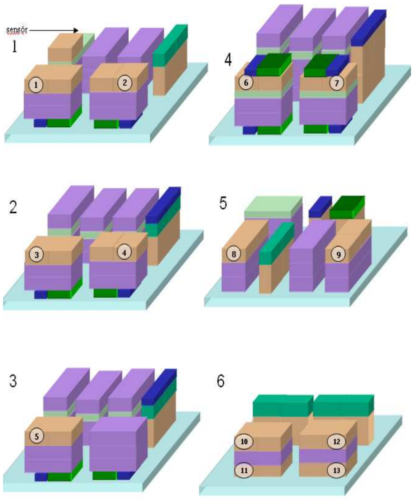
Figure 1 Tube on sheet (TOS) evaporator

SET UP

In this study, the effects of refrigerant circuitry of tube on sheet evaporator on the cooling performance and energy consumption of the freezer have been investigated experimentally [5]. To improve cooling capacity of the refrigeration system, refrigerant was directed to the cooler shelves of evaporator due to the heating effects of refrigerant migration during standstill period.

Freezer cabinet and tube on sheet evaporator (TOS) have 6 shelves as shown in Figure 2. First shelf is the uppermost shelf in the freezer and the lowest shelf is named as the 6th shelf.

(a)



(b)

Figure 2 (a) Freezer cabinet and tube on sheet evaporator (TOS) (b) Temperature measurement points on packages

Temperature, pressure, voltage, current, power and energy consumption values were measured from the test system. The accuracy values of measuring devices are given in Table 1.

Table 1 The accuracy values of measurement devices

Measuring Devices	Brand	Accuracy
Power transducer	Ohio	%0.05
Energy transducer	ION	%0.2
Voltage transducer	Ohio	%0.25
Current transducer	Ohio	%0.25
Pressure transducer	Bourdon Haenni	%0.2
Thermocouples	-	0.02°C

The experiments have been made with measurement packages (as described in ISO15502 standard) at 25 ° C ambient temperature. 3-inch-thermocouples were placed on evaporator shelves for measuring cabinet temperatures. The temperature was measured on the evaporator pipe surfaces. 12 thermocouples are used in the experiments. In addition, the temperatures at inlet and outlet of the compressor, condenser outlet and drier outlet have been measured.

The experiments have been made without thermostat and compressor is controlled with timer. Total run time was kept constant and the experiments have been carried out with same run time (%40) for all the prototypes of the evaporator. The evaporator prototypes have been tested with 48gr R600a refrigerant at 25 °C ambient temperature.

RESULTS

The package temperature distributions in cabinet for different circuitry are given in Table 2. The measuring period for every case is fixing and consists of runtime of 20 min and stop of 30 min.

There are 6 evaporator shelves totally. 1st shelf is the uppermost shelf in the freezer and the bottommost shelf is named as the 6th shelf. Flow circuiting is designed as follows: First, the refrigerant is sent to the 2nd shelf. After that, it is connected to the 1st shelf. It is followed by 6th, 5th, and 4th shelves, as in the written order. Finally, refrigerant is directed to the 3rd shelf and consequently it leaves the evaporator. This is designated as 2-1-6-5-4-3 flow circuiting (B).

Table 2 Package temperature distributions in cabinet for different flow circuiting of evaporator at 25°C ambient energy experiment (Timer control: 20 on, 30 off, %40 RT)

		Flow Circuiting			
		A	B	C	D
		1-2-3-6-5-4	2-1-6-5-4-3	4-1-2-3-6-5	5-6-1-2-3-4
1.shelf	Pk1	-17,3	-19,1	-19,1	-11
	Pk2	-17,6	-18,8	-19,6	-14,9
2.shelf	Pk3	-18,7	-19,2	-20,6	-10,7
	Pk4	-18,8	-19,1	-20,3	-11,25
3. shelf	Pk5	-18,5	-16,5	-20,5	-10,5
4. shelf	Pk6	-16,25	-17	-19,3	-12
	Pk7	-16,7	-17,6	-19,5	-12,2
5. shelf	Pk8	-16,1	-20,3	-15,3	-19,3
	Pk9	-17,85	-20,4	-16,4	-19,3
6. shelf	Pk10	-15,9	-18,5	-14,2	-18,25
	Pk11	-14,9	-17,3	-13,5	-17,3
	Pk12	-15,2	-17,2	-13,9	-17,1
	Pk13	-16,1	-18,3	-14,7	-18,25
	$Pk_{average}$	-16,92	-18,4	-17,45	-14,77

The table shows that in 2-1-6-5-4-3 flow circuiting (B), the hottest packages are the 5th and 6th packages on the 3rd and 4th shelves. The reason of the hottest packages is the 4th shelf of the evaporator hasn't completely filled with liquid refrigerant and the refrigerant has been super-heated phase on the 3rd shelf.

In flow circuitry C, all packages on the 6th shelf that is close to exit and 8th measurement package on the 5th shelf at the evaporator exit are the hottest packages since the refrigerant's super-heated phase come up to these shelves. At flow circuiting D evaporator, since only two shelves at the inlet of the evaporator was filled with liquid phase, the package temperatures on the other shelves were 3-4°C above the average temperature. In this flow circuiting, the packages on the 6th shelf were very colder from the average package temperature because of the fact that the refrigerant enters this shelf in the second turn. But, on the other flow circuiting, the 6th is affected by the temperature of the compressor due to thin insulation.

At the same run time (%40) and same cycle time (sum of compressor on-time and compressor off-time, 50 min.), evaporation and condensation temperatures, the electrical power of the compressor and the energy consumptions are given comparatively in Table 3. According to the Table 3, the hottest measurement package temperature is -16,5° and average package temperature is -18,4 °C on the flow circuiting B evaporator. It can be seen from the table, this flow circuiting evaporator cools much more than the other circuiting's at the same run time. The daily energy consumption is 639 Wh/24h. In flow circuiting D evaporator, the energy consumption is quite high even at the hotter package temperatures according to other flow circuitries. This can be explained that there is a long flow path against the gravity from 6th shelf to 1st shelf.

Table 3 Comparison of the different flow circuiting evaporators at 25°C ambient energy experiment with timer control

Evaporator Flow Circuitry	A	B	C	D
The Hottest Measurement Package Temperature [°C]	-14,9	-16,5	-13,5	-10,5
Average Package Temperature [°C]	-16,92	-18,4	-17,45	-14,77
T_{eva} [°C]	-28,85	-29,25	-29,64	-32,94
T_{cond} [°C]	37,86	37,6	37	27,26
Power [W]	63,77	62,66	64,94	72
Energy Consumption [Wh/24h]	633	639	633	725

In this upright freezer with tube on sheet (TOS) evaporator, reasons such as ascending of hot air because of low density and exit location of supply pipe being near the upper shelf result in inhomogeneous distribution of temperature distribution in the cabinet. Furthermore, heating effect of refrigerant migration when the compressor is not running may increase the temperature of upper shelf. Evaporators' efficiency in the vapor compression refrigeration cycles can be maximized if the cooling system works at the lowest condensing pressures and evaporator is completely filled with liquid refrigerant. It gains importance that evaporator should always be supplied with liquid refrigerant (Low dryness fraction) during the cooling process. Consequently, flow circuiting is very vital in terms of charging the evaporator with liquid refrigerant up to the last shelf.

Experiments have been done 3 times for all evaporator flow circuiting. For the accuracy of the experiments, 'Engineering Equation Solver' (EES) program has been used to calculate uncertainty analysis for the system performance and the result has realized %4,2.

CONCLUSION

In this study, the influence of the evaporator flow circuiting on the performance of the refrigerator has been investigated experimentally. Some experiments have been due to determine of the evaporator performance. Considering these experiments at the upright freezer with tube on sheet evaporator, prototypes have been prepared determining the flow circuiting such that the heating effect of refrigerant migration is directed to cold shelves instead of hot shelves and energy consumption values have been compared.

According to flow circuitry experiments of the evaporator, the hottest measurement package temperature is -16,5°C and average package temperature is -18,4 °C on the flow circuiting B evaporator and have been provided the best cooling performance with the lowest energy consumption compare to the other flow circuitry.

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