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AN EXPERIMENTAL INVESTIGATION ON THE EFFECTS OF MINI CHANNEL CONDENSER IN A HOUSEHOLD REFRIGERATOR-FREEZER

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ABSTRACT

In this study, the effects of parameters as mini channel heat exchanger geometry, refrigerant change and capillary length have been investigated experimentally to improve the cooling system performance and decrease energy consumption. The Design of Experiments (DOE) technique which is a six sigma method has been used to determine simultaneously the individual and combined effects of parameter that could affect the mini channel condenser performance. Energy consumption tests were conducted by considering the same temperatures, which are 5ºC for fresh food compartment and -18ºC freezer compartment, at 25ºC ambient temperature. For the analysis of the results, general linear model method was chosen to identify the effectiveness of the parameters. According to the results, mini channel type and refrigerant charge that are the individual parameters and capillary length-refrigerant charge combined effects are effective but the capillary length and the other combined effects came out to be less effective one. Experiments showed that lowest energy consumption and best cooling performance are performed by shorter capillary length and minimum refrigerant charge.

INTRODUCTION

Mini channel heat exchangers are widely used in air conditioning, heat pump systems and automotive industry to provide more effective system design. Using such heat exchangers enables the transfer of large amounts of heat by providing more heat transfer surface area and high heat transfer efficiency. The implementation of the mini-channel structures have been performed at cooling industry owing to the developments in production and assembly techniques.

In cooling system design, it is possible to decrease energy consumption of a refrigerator by decreasing power of the compressor or by maximizing heat transfer area while keeping the cooling capacity of the system unchanged. Since the work of the compressor will decrease the energy consumption of the products will decrease. Downsizing of the cooling components has been a necessity as a result of emerging technology and increased material costs. These objectives will be realized with the mini-channel technology.

NOMENCLATURE

a	[mm]	Distance between the passes of the condenser
A_{Tot}	[m^2]	Total heat transfer area of the condenser
F_p	[mm]	Fin pitch
H	[mm]	Height of the condenser
W	[mm]	Width of the condenser

Kohl et. Al [1] have been conducted to investigate discrepancies in previously published data for the pressure drop in microchannels experimentally. Straight channel test sections with integrated pressure sensors were developed with channel hydraulic diameters ranging from 25 to 100 μm. Compressible flow results for $6.8 < Re < 18{,}814$ and incompressible flow results for $4.9 < Re < 2068$ have been obtained. The results suggest that friction factors for microchannels can be accurately determined from data for standard large channels. The large inconsistencies in previously published data are probably due to instrumentation errors and/or improper accounting for compressibility effects.

Experimental heat transfer studies during condensation of pure R-134a vapor inside a single microfin tube have been carried out by Akhavan-Behabadi et al [2]. The microfin tube has been provided with different tube inclination angles of the direction of fluid flow from horizontal, a. A correlation has also been developed to predict the condensing side heat transfer coefficient for different vapor qualities and mass velocities. A generalized finite volume-based model to simulate

Microchannel Heat Exchangers (MCHXs) with variable tube and fin geometries using a three-stream UA-AMTD method is presented by Huang et al [3]. The model is validated against 227 experimental data points for eight different fluids, and eighteen MCHX geometries, including four different variable geometry microchannel condensers. The hydrodynamic and thermal performance of two deep microchannel configurations have been investigated both theoretically and experimentally by Harms et al. [4]. All tests were performed with deionized water as the working fluid, where the Reynolds number ranged from 173 to 12 900. The experimentally obtained local Nusselt number agrees reasonably well with classical developing channel flow theory. Furthermore, the results show that, in terms of flow and heat transfer characteristics, our microchannel system designed for developing laminar flow outperforms the comparable single channel system designed for turbulent flow.

Park and Hrnjak [5], investigated the effect of different type of condensers on the performance of R410A residential air conditioning systems. Two R410A residential air-conditioning systems, one with a microchannel condenser and the other with a round-tube condenser, were examined experimentally, while the other components of the two systems were identical except the condensers. The results were showed that both the COP and cooling capacity of the system with the microchannel condenser were higher than those for the round-tube condenser in all test conditions. The refrigerant charge amount for the system with the microchannel condenser was 9.2% smaller than that with the round-tube condenser. A number of compact prototype heat exchangers for CO_2 air-conditioning systems have been designed and built, and performance tests have been conducted under realistic operating conditions by Pettersent et al. [6]. Compact heat exchangers have been optimized for CO_2 are very competitive with baseline units in terms of physical dimensions, mass and performance. Shen et al. [7], investigated the single phase convective heat transfer in a compact heat sink consisting of 26 rectangular microchannels of 300 μm width and 800 μm depth experimentally. The relative roughness is estimated to be 4–6%. Deionized water was used as the working fluid. Tests were performed with the Reynolds number range of 162–1257, the inlet liquid temperatures of 30, 50 and 70°C and the heating powers of 140–450 W. The planform area is 5.0x1.53 cm^2. They found that the friction factors and local and average Nusselt numbers significantly depart from those of conventional theories, possibly attributable to the surface roughness. Correlations were provided for the friction factors and the Nusselt numbers.

Rands et al [8], have been studied characterizing the laminar-turbulent transition for water flow in circular microtubes experimentally. Measurements of the frictional pressure drop and viscous heating-induced temperature rise were made for water flowing through fused silica microtubes. Over 240 independent experimental conditions were explored for microtube diameters ranging from 16.6 to 32.2 μm spanning the Reynolds number range $300 < Re < 3400$. Classical laminar flow behavior was confirmed at low Reynolds numbers. The onset of transition from laminar to turbulent flow was observed using two independent approaches to occur at Recr = 2100–2500.

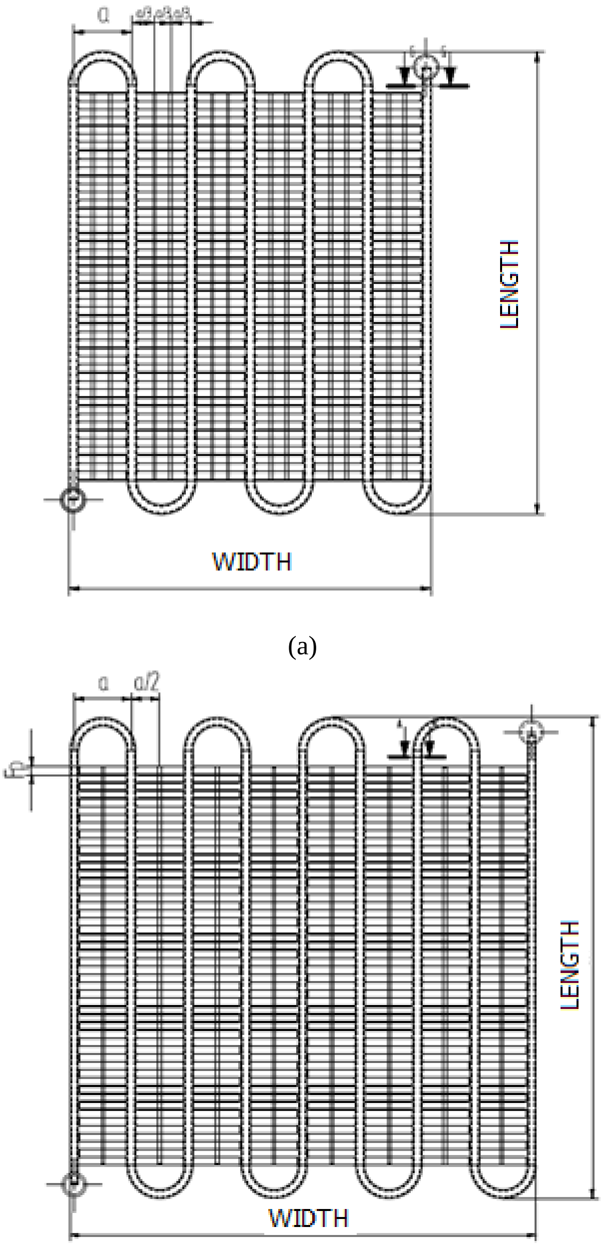
Ribeiro et al [9], investigated the thermal-hydraulic performance of microchannel condensers with open-cell metal foams to enhance the air-side heat transfer. Three different copper metal foam structures with distinct pore densities (10 and 20 PPI) and porosities (0.893 and 0.947) were tested. A conventional condenser surface, with copper plain fins, was also tested for performance comparison purposes. The experimental apparatus consisted of a closed-loop wind tunnel calorimeter and a refrigerant loop, which allowed the specification of the mass flow rate and thermodynamic state of R-600a at the condenser inlet. The experiments were performed at a condensing temperature of 45 °C. The air-side flow rate ranged from 1.4×10^{-3} to 3.3×10^{-3} m^3/s (giving face velocities in the range of 2.1–4.9 m/s). The heat transfer rate, the overall thermal conductance, the Colburn j-factor, the friction factor and the pumping power were calculated as part of the analysis. Two-phase pressure loss of R134a in microchannel headers has been analyzed experimentally by Coleman and Krause [10]. Novel experimental techniques and test sections were developed to enable the accurate determination of the minor losses without obfuscating the problem with a lengthwise pressure gradient. Pressure losses were recorded over the entire range of qualities from 100% vapor to 100% liquid. The tests were conducted for five different refrigerant mass fluxes between 185 and 785 $kg/m^2{\cdot}s$. The observed pressure losses were correlated to a momentum model and its application should be restricted to contraction losses for microchannel tube and header geometries.

As it seen in the literature, the mini channel condenser of household refrigerator-freezer has not been investigated. Therefore, the comparison of two mini channel type and the effects of mini channel condenser geometry, refrigerant amount and capillary length on the refrigeration system performance have been done experimentally in this study.

EXPERIMENTAL SETUP

In this study, the effects of parameters as mini channel heat exchanger geometry, refrigerant amount and capillary length have been investigated experimentally to improve the cooling system performance and decrease energy consumption. Design of Experiments (DOE) technique which is a six sigma method was used to determine simultaneously the individual and combined effects of parameters that could affect the mini channel condenser performance.

Two condensers were designed as shown in Figure 1a and 1b. Dimensional parameters are listed in Table 1.



(b)

Figure 1 Technical drawings of mini channel condensers
(a) Sample 1 (b) Sample 2

Table 1 Dimensions of Mini Channel Condensers

Sample No	F_p (mm)	W (mm)	H (mm)	a (mm)	A_{tot} (m^2)
1	2,8	160	160	25,8	0,316
2	2,8	160	160	17	0,383

These samples are mounted to a household refrigerator-freezer as shown in Figure 2.

Figure 2 Mini channel condenser sample

The refrigerator-freezer is placed in a testing chamber which is conditioned as required in ISO 15502 standard at 25ºC ambient temperature to record inner temperatures and energy consumption..

Thermocouples are used to measure the temperatures in the system. Inner temperatures of the cabinets in the refrigerator-freezer are monitored to ensure that ISO 15502 standard requirements are met. Energy consumption is measured while freshfood compartment average air temperature is between 0ºC and 5ºC, and maximum freezer compartment temperature is lower than -18ºC. Power consumption is measured by using Ohio brand power sensor and energy consumption is measured ION brand sensor.

Calibration of the thermocouples, power and energy sensors are done by FLUKE 5500 calibrator.

EXPERIMENTS

The Design of Experiments (DOE) technique which is a six sigma method has been used to determine simultaneously the individual and combined effects of parameter that could affect the mini channel condenser performance on a household refrigerator-freezer. In this design, 2 different mini channel condensers, capillary tubes at 3 different lengths, and R600a refrigerant at 3 different amounts are chosen as experiment parameters. Energy consumption tests are conducted at 25ºC ambient temperature with these parameters. In DOE, 18 different experiments are planned to validate the differences between the effects of parameters. These parameters are listed in Table 2.

Table 2 Parameters in DOE

Condenser Type	Capillary Tube Length	Refrigerant Amount
Sample 1	3000 mm	50 g
Sample 2	3500 mm	60 g
	4000 mm	70 g

RESULTS

Energy consumption of household refrigerator-freezer with 2 different mini channel condenser performances has been compared. 18 different experiments were carried out to investigate the differences between the effects of parameters such as mini channel heat exchanger geometry, refrigerant amount and capillary tube length. Test results conducted according to DOE are shown in Table 3.

Table 3 Test results conducted according to DOE

Condenser Type	Refrigerant amount (g)	Capillary Tube Length (mm)	Energy Consumption (kwh/day)
Sample 1	50	3000	0.938
Sample 1	50	3500	1.199
Sample 1	50	4000	1.589
Sample 1	60	3000	1.151
Sample 1	60	3500	1.282
Sample 1	60	4000	1.472
Sample 1	70	3000	1.219
Sample 1	70	3500	1.342
Sample 1	70	4000	1.401
Sample 2	50	3000	1.124
Sample 2	50	3500	1.281
Sample 2	50	4000	1.625
Sample 2	60	3000	1.266
Sample 2	60	3500	1.340
Sample 2	60	4000	1.592
Sample 2	70	3000	1.302
Sample 2	70	3500	1.475
Sample 2	70	4000	1.530
Sample 1	50	3000	0.948
Sample 1	50	3500	1.197
Sample 1	50	4000	1.598
Sample 1	60	3000	1.148
Sample 1	60	3500	1.280
Sample 1	60	4000	1.470
Sample 1	70	3000	1.224
Sample 1	70	3500	1.351
Sample 1	70	4000	1.399
Sample 2	50	3000	1.121
Sample 2	50	3500	1.276
Sample 2	50	4000	1.624
Sample 2	60	3000	1.264
Sample 2	60	3500	1.349
Sample 2	60	4000	1.589
Sample 2	70	3000	1.298
Sample 2	70	3500	1.484
Sample 2	70	4000	1.536

For the analysis of the experiments results, general linear model method was chosen to determine the effects of the parameters. The results are summarized and presented graphically in this section.

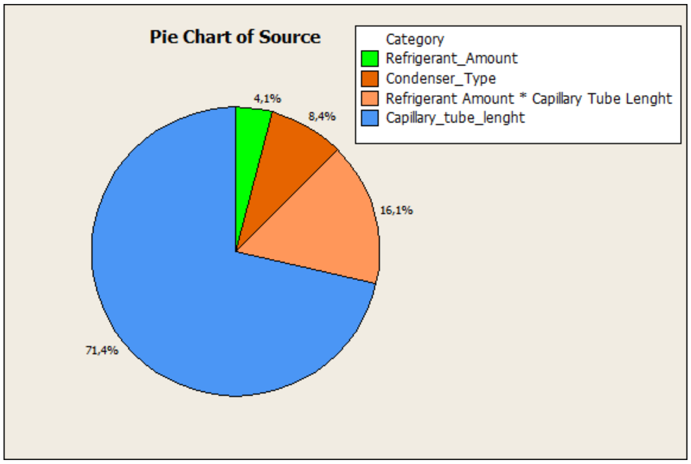


Figure 3 Pie chart of parameters

According to experimental results, effects of variation of parameters on energy consumption are presented in Figure 2. Most effective parameters are found as capillary tube length, condenser type and combination of refrigerant amount and capillary tube length.

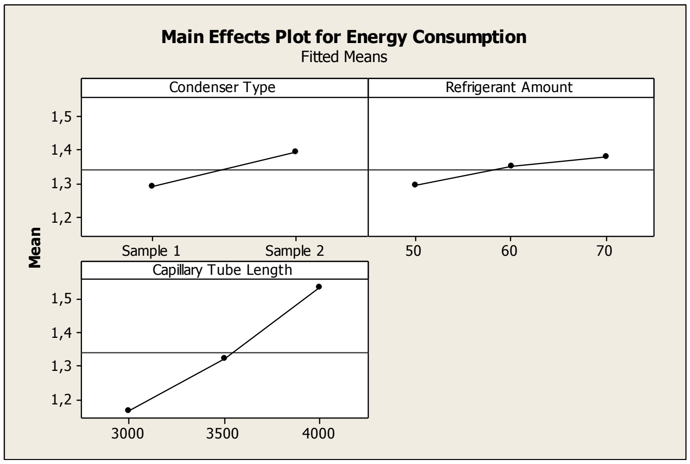


Figure 4 Main effects of parameters on energy consumption

According to the results, it is seen from the graphic that energy consumption increases as the refrigerant amount increases. When the capillary tube length is changed from 4000 mm to 3000 mm, energy consumption is decreased drastically. The parameters which provide minimum energy consumption are mini channel condenser type 1, 3000 mm capillary tube length and 50 g refrigerant amount.

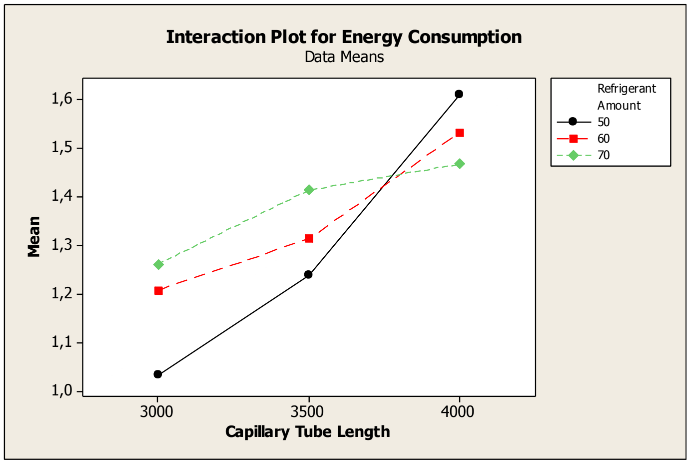


Figure 5 Combined effects of capillary tube length and refrigerant amount

The variation of energy consumption according to capillary length and refrigerant amount is given in Figure 5. Also combined effects of capillary tube length and refrigerant amount are seen on the graph. It is seen from the graphic that when the capillary tube length 3000 mm and 3500 mm, 50 g refrigerant amounts gave better energy performance.

Consequently, energy consumption of the household refrigerator-freezer is found as 0.943 kWh/day which is better than the nominal energy consumption of this product (1.043 kWh/day) with conventional condenser.

CONCLUSION

In this study, performance of two different types of mini channel condenser has been compared with conventional condenser when the capillary tube length and refrigerant amount is changed. The energy consumption of refrigerator is measured with different parameters such as mini channel condenser type, capillary tube length and refrigerant amount and the experimental results have been analysed with using general linear model method.

Experimental results indicate that most effective parameters are found as capillary tube length, condenser type and combination of refrigerant amount and capillary tube length on the energy consumption of refrigerator-freezer.

Test results show that condenser type 1, capillary tube with 3000 mm length and 50 g of refrigerant combination gave the least energy consumption which is the goal of this experiment.

Energy consumption is found 10% better than energy consumption of existing product with conventional condenser.

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