Study, and Testing of a Split-Type Air Conditioning Unit by Using Microchannel Condenser

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Abstract

The microchannel heat exchangers are widely used in automobile air conditioning systems. Thus, this research aimed to develop, study, and test a split type air conditioning system by using microchannel heat exchanger at a condenser. The split type air conditioning unit with a cooling capacity of 18,000 Btu/hr was used in this study. The microchannel condenser was constructed of multiport microchannel aluminum tubes having two rows of horizontally aligned serpentine heat exchangers in series. The condenser was installed in a wind tunnel in order to maintain the inlet air temperature and to measure the temperatures and air flow rate. The performances of microchannel and fin-and-tube condensers were investigated and compared by having the same air-side heat transfer area and heat exchanger volume. The effects of the condenser inlet air temperatures on the condenser heat rejection rate, effectiveness, and energy efficiency ratios (EER) were examined.

The test results showed that the heat rejection rates of microchannel condenser were lower than those of fin-and-tube condenser, at the given condenser air inlet temperatures of 35°C, 38°C, and 42°C, by 0.28%, 1.39%, and 0.45%, respectively. However, as the condenser air inlet temperatures increased from 35°C to 38°C and to 42°C, the effectivenesses of microchannel condenser were higher than those of fin-and-tube condenser by 3.66%, 5.65%, and 3.64%, respectively. The EERs of the split type air conditioning system with the microchannel condenser were higher than those of the system with the fin-and-tube condenser as the condenser air inlet temperatures were increased from 35°C to 38°C and to 42°C by 1.14%, 3.08%, and 2.80%, respectively.

Key words: air conditioning unit, condenser, microchannel, fin-and–tube.

Nomenclature

c	Specific heat (J/kg-K)
COP	Coefficient of performance (-)
EER	Energy efficiency ratio (%)
F&T	Fin-and-tube condenser
h	Enthalpy (J/kg-K)
MHX	Microchannel condenser
$\dot{m}$	Mass flow rate (kg/s)
$\dot{Q}$	Heat loss or heat transfer (W)
T	Temperature (^{o}C)
$\dot{W}$	Power input (W)

Greek symbols

ε	Heat exchanger effectiveness (%)

Subscripts

a	Ambient air or air
comp	Compressor
cond	Condenser
elec	Electric
evap	Evaporator
i	Inlet, inner
max	maximum
o	Outlet
r	Refrigerant
tot	Total

1. Introduction

The split-type air conditioning systems are widely used in houses, little offices and buildings for cooling the occupants in the building.

Normally, the heat exchangers of the split-type air conditioning system are fin and tube heat exchangers. While, a microchannel heat exchanger is widely used in the automotive air conditioning system.

The enhanced performance and efficiency improvement of microchannel technology were the results of higher air-side heat transfer, higher refrigerant side heat transfer, and high fin-to-tube surface contact [1]. The enhanced microchannel thermal performance had the potential permit equivalent system design with up to 25% reduction in the overall coil size comparing to the conventional fin-and-tube coils. A wind tunnel was build to examine both a fin-and-tube and microchannel condensers in the air conditioning applications. The energy efficiency ratio (EER), heat transfer rate at condenser, and the power consumption were focused in this study.

Hrnjak [2] studied the effects of different type of condensers on the performance of R410A for the residential air conditioning systems. Two R-410A residential air-conditioning systems, one with a microchannel condenser and the other with a round-tube condenser, were experimentally examined, while the other components of the two systems were identical except the condensers. The COP of the system with the microchannel condenser was 13.1% higher than that with the round condenser in ARI A condition.

Qi, Zhao, and Chen [3] proposed that two retrofitted compact and high efficient microchannel heat exchangers. The heat transfer characteristics were compared with the currently used heat exchangers in mobile air conditioning (MAC) industry. One enhanced and one baseline R-134a MAC systems were established including the new microchannel heat exchangers and the traditional laminated type heat exchangers. The coefficient of performance (COP) of the enhanced system was slightly lower than that of the baseline system under idle conditions but higher under all the other test conditions. The cooling capacity and COP of the enhanced system were increased by about 5% and 8%, respectively under high vehicle speed conditions.

Kraitong [4] A Case Study of Waste Heat Recovery This apparatus was used for exchanging heat between 65°C hot water and ambient air. Parameters considered in this investigation were the mass flow rate of air stream, which ranged between 0.1 and 0.4 kg/s; the number of condensers which were 1-3 sets; and the flow patterns of hot water and ambient air with two variations, i.e., counter flow and parallel flow. It was found that the calculated effectiveness was between 0.4 and 0.9 depending on the mass flow rate of air.

In this study, the spit type air conditioning systems using the fin-and-tube and microchannel condensers will be constructed and investigated by varying the condenser air inlet temperatures between 35°C and 42°C. The test results (cooling capacity, condenser heat rejection rate, condenser effectiveness, and energy efficiency ratio) of the fin-and-tube condenser system will be compared with that of the microchannel condenser system.

2. Experimental set up

A split type air conditioning unit with a cooling capacity of 18,000 Btu/hr was used in this study. The condenser was dismantled from the original system and installed in a wind tunnel in order to maintain the condenser air inlet temperature by using two heaters of 1500 W each, and measure the condenser air inlet and outlet temperatures and air flow rate, according to ANSI/ASHRAE 41.2-1987 Standard [5].

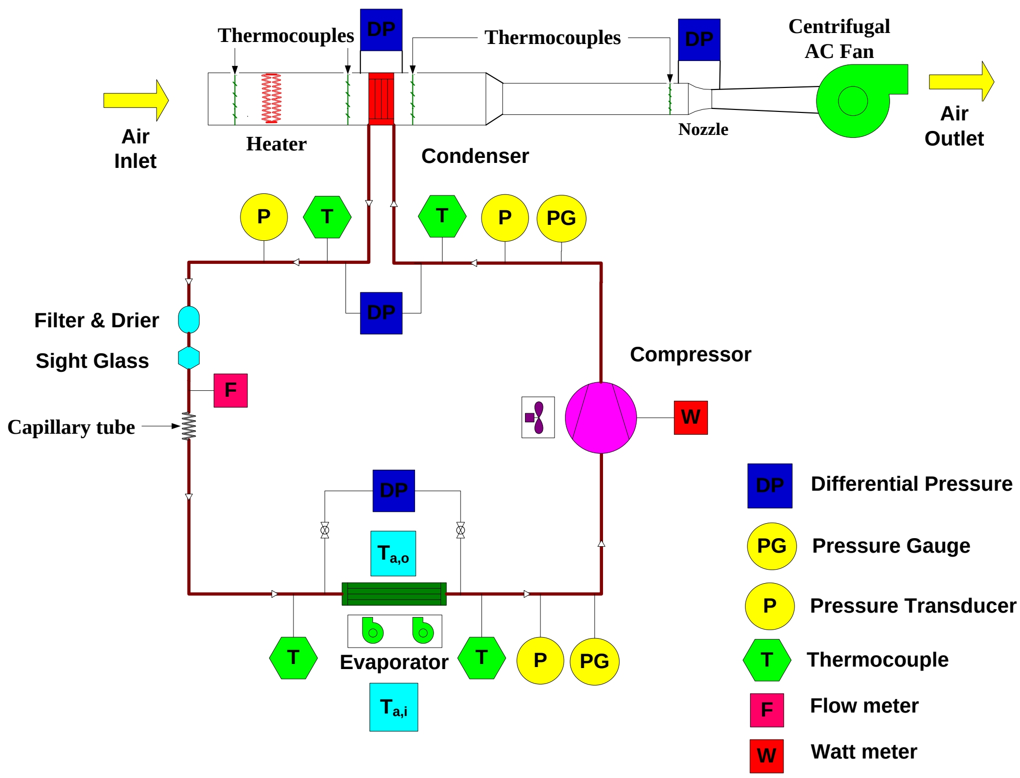


Fig. 1 Schematic diagram of split type air conditioning system with capacity of 18,000 Btu/hr.

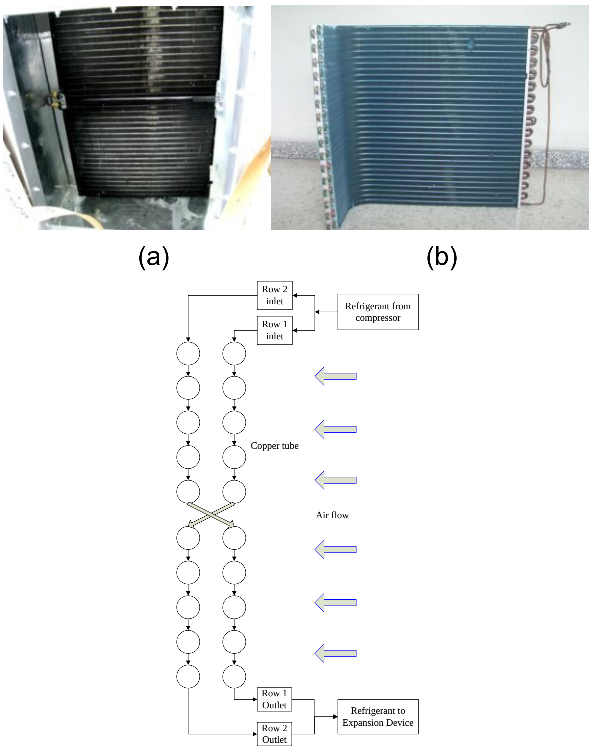
Fig. 1 shows a layout of the system test facilities and instrumentations. The resistance heaters were installed at the inlet of air duct for controlling the condenser inlet air temperature. A centrifugal fan (from Kruger Ventilation Industries (Thailand) Co. Ltd.) with maximum flow rate of 1360 m^3/hr and static pressure of 1025 Pa was placed at the downstream of the wind tunnel.

All temperature measurements were T-type thermocouples. Differential pressure transmitters were installed on the air-side across a condenser and a nozzle. The condenser air flow rate was determined from the measured pressure drop of a nozzle. For the refrigerant-side, a high pressure transducer ranged from 0 to 25 bar was installed at the inlet of the condenser for R-22 unitary air conditioner. A low pressure transducer ranged from 0 to 16 bar was installed at the outlet of the evaporator. Two differential pressure transmitters were installed on the refrigerant-side across the condenser and evaporator for pressure drop measurement. The coriolis mass flow meter was installed between the condenser and needle valve. All data were collected and saved using data acquisition: Agilent model 34980A.

The microchannel and fin-and-tube condensers were selected with the conditions to have the same fin area and volume. The criteria on the air side were imposed in order to evaluate the effect of the refrigerant tube size on the heat transfer rate and effectiveness of the condenser. The detail characteristics of both condensers are shown in Table. 1. The condenser was constructed of multiport microchannel aluminum tubes having two rows of horizontally aligned serpentine condensers in series. The fin-and-tube condenser had two parallel circuits and 32 passes per circuit. The photographs of microchannel, fin-and-tube condensers, and fin-and-tube condenser refrigerant flow circuit were illustrated in Fig. 2 (a), (b), and (c), respectively.

Table. 1 shows properties of both condensers

	Microchannel	Fin-and-tube
Volume (cm^3)	23,233	23,800
Fin density (fins/cm)	7	6
Tube material	Aluminum	Copper
Total fin area (cm^2)	234,328	229,840
Fin type	Folded louver	Offset strip
Pass	1 circuit	2 circuits
Unit	2 units in series	2 unit in parallel



(c)

Fig. 2 (a) Microchannel condenser, (b) fin-and-tube condenser, (c) fin-and-tube condenser refrigerant flow circuit.

The following assumptions were used in the testing fin-and-tube and microchannel condensers: (a) Ambient temperature were 25 $\pm$ 2°C; (b) Refrigerant system pressure of both systems were equal; (c) Refrigerant charge of microchannel condenser system was less than that of fin-and-tube system.

3. Method

The enthalpies of air and refrigerant were calculated from known pressures and temperatures by using the thermodynamic property functions of the Engineering Equation Solver (EES) [6].

The air-side heat transfer rate of the condenser was calculated by multiplying the refrigerant mass flow with the refrigerant enthalpies difference across the condenser:

$$\dot{Q}_{cond,a} = \dot{m}_a (h_{a,o} - h_{a.i}) \tag{1}$$

where the air mass flow rate of was obtained from measuring pressure drop across the nozzle installed in the wind tunnel.

The refrigerant-side heat transfer rate of the condenser was calculated by multiplying refrigerant mass flow rate with the refrigerant enthalpies difference across the condenser:

$$\dot{Q}_{cond,r} = \dot{m}_r (h_{cond,i} - h_{cond,o}) \tag{2}$$

where the refrigerant mass flow rate of was measured by using the coriolis flow meter installed between the condenser and expansion device.

The effectiveness of condenser is the ratio between the actual heat transfer rate (refrigerant side heat transfer rate) and the maximum heat transfer rate of condenser.

$$\varepsilon = \frac{\dot{Q}_{cond,r}}{\dot{Q}_{cond,\max}} \tag{3}$$

where the maximum is the product of the minimum heat capacity and the maximum heat temperature difference. The latter was calculated as the difference between the saturated temperature of the refrigerant at inlet pressure and air temperature at the condenser inlet

$$\dot{Q}_{cond,\max} = \dot{m}_a c_a (T_{sat@P=P_{cond.i}} - T_{air.i}) \tag{4}$$

The refrigerant-side heat transfer rate of the evaporator or cooling capacity was determined by multiplying refrigerant mass flow rate with the refrigerant enthalpies difference across the evaporator:

$$\dot{Q}_{evap,r} = \dot{m}_r (h_{evap,o} - h_{evap,i}) \tag{5}$$

The energy efficiency ratio (EER) of air conditioning system is determined by

$$EER = \frac{\dot{Q}_{evap,r,Btu}}{\dot{W}_{tot,elec}} \tag{6}$$

Where $\dot{W}_{tot,elec}$ is the total electrical powers of compressor, evaporator fan.

4. Results and Discussion

Temperatures and pressures, refrigerant mass flow rate, and compressor power as shown in Table. 2 were measured at a steady state conditions for every 2 minutes of 50 minutes testing period. The air conditioning systems with fin-and-tube condenser and microchannel condenser subjected to identical fin surface area and heat exchanger volume were compared by varying the condenser air inlet temperatures from 35° to 42°C.

Table. 2. Measurement data of air conditioning systems using fin-and-tube and microchannel condensers.

Condenser type	$T_{air,i}$ [ºC]	$T_{air,o}$ [ºC]	$T_{comp,i}$ [ºC]	$T_{comp,o}$ [ºC]	$T_{cond,o}$ [ºC]	P_S [kPa]	P_D [kPa]	PR [-]	$\dot{m}_r$ [g/s]	$\dot{W}_{comp,e}$ [W]
Fin-and-tube	34.1	42.9	16.4	60.3	42.94	542.3	2174.3	4.01	28.37	1.339
	38.1	44.5	13.0	59.5	44.48	545.2	2233.0	4.10	28.82	1.345
	41.8	46.3	10.5	60.4	46.33	551.6	2308.4	4.18	29.21	1.345
Microchannel	35.3	44.1	12.4	61.5	44.11	546.7	2190.5	4.01	28.82	1.345
	38.9	45.1	9.0	58.9	45.14	546.5	2241.5	4.10	28.79	1.269
	42.7	47.1	9.4	60.6	47.13	561.0	2327.5	4.15	29.32	1.296

Table. 3 illustrated the cooling capacities, condenser heat rejection rates, condenser effectivenesses, and energy efficiency ratios (EERs) were determined for the spit type air conditioning systems of 18,000 Btu/hr using the fin-and-tube and microchannel condensers. The values at a given condenser air inlet temperature in Table. 2 and Table. 3 were the average values from the testing period of three repeated tests.

Table. 3. Calculated performance results of air conditioning systems.

Condenser type	$T_{air,i}$ [ºC]	$\dot{Q}_{evap,r}$ [Btu/hr]	$\dot{Q}_{cond,r}$ [kW]	ε_{cond} [%]	EER_{act} [Btuh/W]
Fin-and-tube	34.1	16,849	5.15	41.66	12.58
	38.1	16,723	5.13	34.85	12.43
	41.8	16,542	5.12	28.13	12.29
Microchannel	35.3	16,391	5.13	43.45	12.70
	38.9	16,276	5.06	35.19	12.82
	42.7	16,374	5.09	28.48	12.63

For split type air conditioning system with fin-and-tube condenser, the cooling capacities, condenser heat rejection rates, condenser effectivenesses, and EERs decrease with increasing condenser air inlet temperatures at fixed condenser air flow rate as shown in Table. 3, probably because of the higher discharge pressures. The same trends are for the system with microchannel condenser except for the condenser air inlet temperature of 38^{O}C that the values increase with increasing condenser air inlet temperatures. This is owing to the lower refrigerant mass flow rate and lower electrical compressor power.

From Table. 3, the cooling capacities of the system with fin-and-tube condenser are higher than those of the system with microchannel condenser by 2.72%, 2.67%, and 1.02%, at condenser air inlet temperature varying from 35^{O}C, 38^{O}C, and 42^{O}C, respectively. However, the EERs of the system with fin-and-tube condenser are lower than those of the system with microchannel condenser by 1.14%, 3.08%, and 2.80%, at condenser air inlet temperature varying from 35^{O}C, 38^{O}C, and 42^{O}C, respectively. Therefore, the maximum EER occurs at the condenser air inlet temperature of 38^{O}C for the split type air conditioning system with microchannel condenser as shown in Fig. 3.

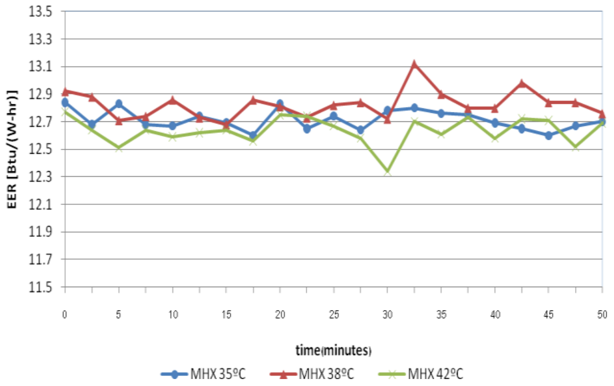


Fig. 3 Energy efficiency ratios of split type air condition with microchannel condenser at condenser air inlet temperatures ranging from 35°C to 42°C.

Fig. 4 and Fig. 5 show the condenser heat rejection rates and EERs of both systems at the condenser air inlet temperature of 38°C for steady state conditions. At this condenser air inlet temperature, the condenser heat rejection rate and EER of the microchannel condenser system are higher than that of the fin-and-tube condenser system by 1.39% and 3.08%, respectively.

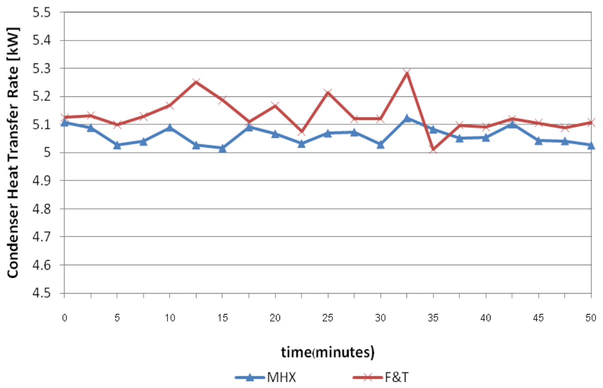


Fig. 4 Condenser heat rejection rates at condenser air inlet temperature of 38°C

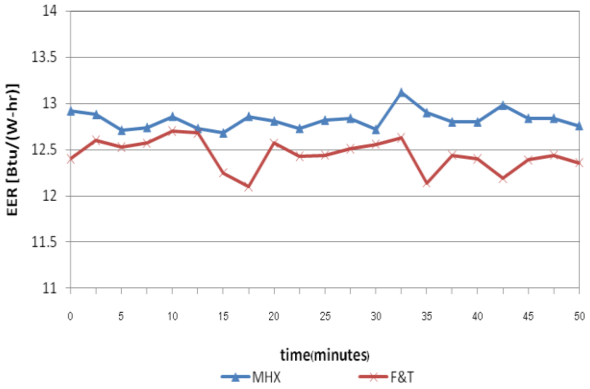


Fig. 5 Energy efficiency ratios at condenser air inlet temperature of 38°C

5. Conclusions

A bread board split type air conditioning system with the cooling capacity of 18,000 Btu/hr by using fin-and-tube and microchannel condensers was designed, built, and tested in the wind tunnel. The aluminum microchannel condenser had two rows of serpentine heat exchangers in series while the fin-and-tube condenser had two parallel heat exchanger slabs. The microchannel and fin-and-tube condensers were investigated with the criteria of having the same fin area and volume. The air side conditions were enforced in order to assess the effect of the refrigerant tube size on the heat transfer rate and effectiveness of the condenser.

The experimental results showed that the energy efficiency ratios (EERs) of split type air conditioning with microchannel condenser were higher than those of the system with the fin-and-tube condenser by 1.14%, 3.08%, and 2.80%, at condenser air inlet temperature varying from 35°C, 38°C, and 42°C, respectively. The cooling capacity of the systems were ranged from 16,280 to 16,850 Btu/hr, which was approximately 90-94% of the rated capacity.

In future, the split type air conditioning system with microchannel condenser will be investigated for the case where two rows of the aluminum microchannel condenser are in parallel.

6. Acknowledgements

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7. References

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