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Experimentation on a Tube in tube Condenser for Water Heating from an Air-conditioner

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ABSTRACT

This paper introduces air-conditioning product that can achieve the multi-functions with improved energy performance. The basic design principles and the laboratory test results are presented. The results showed that by incorporating a water heater in the out- door unit of a split-type air-conditioner so that space cooling and water heating can take place simultaneously, the energy performance can be raised considerably. That removes heat from the source at low temperature to the sink at high temperature by using mechanical work. Normally, it uses the same basic refrigeration cycle.

The cost share of a storage unit is larger in a domestic storage air conditioner system than in a commercial storage air conditioner. Moreover, the domestic air conditioner is characterized with a compact structure and relatively installation space. For that reasons the development of domestic air-cooled air-conditioner into the water-cooled air-conditioner with the storage function added into it for the heat recovery.

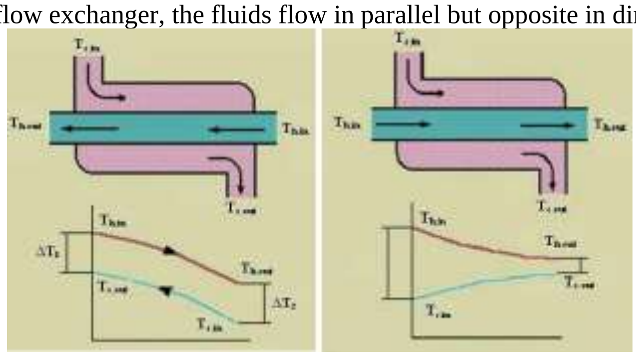
In the present study, we intend to develop a water-cooled technology for residential split-type air-conditioner to have higher COP than the standard value of 2.96. The performance of the water-cooled condenser could be elevated by improving the air–water cooling design using a special filling material. A cross-flow type cooling tower is taken to compromise with the installation space.

1. NUMERICAL DESCRIPTION

A heat recovery unit is a special purpose heat exchanger specifically designed for the object of:

1. Extraction the heat from the condensation process in an effective manner.
2. Improvement in the overall system efficiency by the new condenser.
3. Protection against contamination of potable water.
4. Offering mechanically clean ability to quickly restore full capacity.
5. Minimal pressure drops across the heat exchanger to minimize the pumping losses.

In the present experimentation, the type of heat exchanger to be tested is the counter flow tube in tube heat exchanger. In the counter flow exchanger, the fluids flow in parallel but opposite in directions.



(a) Counter flow *(b) Parallel flow*

Fig 6.3: Counter flow and parallel flow of liquid inside tube

Consider the double-pipe heat exchanger shown in Fig. The rate of heat transfer depends mainly upon

- Thermal conductivity
- Area of heat transfer
- Temperature difference

Using the equation of conservation of energy,

$$\frac{K}{l} A_i (T_{h.in} - T_{h.out}) = U A_o (T_{c.out} - T_{c.in})$$

For inner tube, we have

K = Thermal conductivity

A_i = Cross-sectional area of inner tube

$= \frac{\pi}{4} \times d_i^2$ (in m^2)

$T_{h.in}$ = Inlet temperature of the hot fluid flowing through inner tube

$T_{h.out}$ = Outlet temperature of the hot fluid flowing through inner tube

For outer tube,
U = Overall heat transfer coefficient (in W/m^2K)
A_o = Cross-sectional area of outer tube = $\frac{\pi}{4} \times d_o^2$ (in m^2)
$T_{c.in}$ = Inlet temperature of the cold fluid flowing through outer tube
$T_{c.out}$ = Outlet temperature of the cold fluid flowing through outer tube

1.1 Effectiveness of a heat exchanger:

It is defined as the ratio of the actual heat transferred by the heat exchanger to the maximum amount of heat that can be transferred by the same heat exchanger. Mathematically,

$$\varepsilon = \frac{\text{Actual heat transferred}}{\text{Maximum heat to be transferred}}$$

Also,

The refrigerating effect of the system can be calculated as: R. E. = m C_p (t_1-t_2)
The work done by the compressor on the refrigerant is ginen as- W = m C_p (t_1-t_2)
The co-efficient of performance of the system is given as- COP = $\frac{R.E.}{W}$

2. DESIGN OF TUBE IN TUBE CONDENSER

2.1 Design Considerations

In designing heat exchangers, a number of factors that need to be considered are:

1. Resistance to heat transfer should be minimized.
2. Contingencies should be anticipated via safety margins; for example, allowance for fouling during operation.
3. The equipment should be sturdy.
4. Cost and material requirements should be kept low.
5. Corrosion should be avoided.
6. Pumping cost should be kept low.
7. Space required should be kept low.
8. Required weight should be kept low.

2.2 Design and Construction

The inner tube used through which the refrigerant flow is made of copper. The design calculations for this condenser are as follows:

Using the equation of conservation of energy,

The heat transferred by the refrigerant = The heat absorbed by water flowing at the copper tube through the outer tube

$$\frac{K}{l} A_i (T_{h.in} - T_{h.out}) = U A_o (T_{c.out} - T_{c.in})$$

For inner copper tube, we have
K = Thermal conductivity = 400 W/mK
A_i = Cross-sectional area of copper tube
$= \frac{\pi}{4} \times (0.00635)^2 = 0.0000317\ m^2$

$T_{h.in}$ = Maximum temperature of the refrigerant achieved at the copper tube at the entry to the condenser during the water dipped readings = 91 °C

$T_{h.out}$ = Maximum temperature of the refrigerant achieved at the copper tube at the exit to the condenser during the water dipped readings = 50 °C

For outer tube,
U = Overall heat transfer coefficient = 13.4 W/m^2K
A_o = Cross-sectional area of outer tube
$= \frac{\pi}{4} \times (0.01905)^2 = 0.000285\ m^2$

$T_{c.in}$ = Mean temperature of the water at the atmospheric conditions during the water dipped readings = 26 °C

$T_{c.out}$ = Maximum temperature of the water achieved when the copper tube transfers the heat to water during the water dipped readings = 56 °C Thus, we get,

$$\frac{400}{l} \times 0.0000317 \times (91\text{-}50) = 13.4 \times 0.000285 \times (56\text{-}26)$$

l = 4.5377 m = 14.8876 ft ≈ 15 ft

Hence, the length of the inner copper tube which is to be cooled by passing the water above it is 15 feet.

For the construction of the tube in tube condenser, the copper tube of diameter 0.25" was used as the inner tube for the flow of refrigerant whereas the commonly available PVC pipe for the water supply of diameter of 0.75" was used through which the cold water was passed.

3. EXPERIMENTAL APPARATUS AND PROCEDURE

The system under experimentation mainly consists of an evaporator, air cooled condenser, water cooled tube in tube condenser, compressor, capillary tube, reservoir tank and feed water valve. The air conditioner with cooling capacity of 1 TR is used as a common cycle. Then, a tube in tube water cooled condenser is added into the system for the heat recovery. Evaporator is placed in a control room with dimension of 68 m^2. Room temperature is kept at 24 ^{0}C. In the present experimentation, refrigerant R-22 is used as a working fluid. The bourdon pressure gauge and the thermocouples are mounted at the both ends of the evaporator, air cooled condenser and water cooled condenser to measure pressure and refrigerant temperature, respectively.

Similarly, a power-meter is used to measure power consumption of the system. Focused on the water cooled condenser, the coil made from copper tube having diameter 0.25 inches is allowed to pass through a tube of diameter 0.75 inches. The outer tube is made from a polymer that is used for household water pumping. The thermocouple ends are inserted at inlet and outlet flow of water. The flow of cooling water is adjusted at 160, 200, 260, 305 & 345 liters/hr. A feed water valve is used to control flow rate of water through the outer tube. When the required value of temperature in the room is reached, the room thermostat switches the unit off.

In this study, the bourdon pressure gauges were calibrated by the manufacturer. Similarly, all measuring temperature devices are well calibrated using electronic temperature sensors. The uncertainty of all temperature measurement after considering the data acquisition system is 1 ^{0}C. During the test run, pressure and temperature at the inlet and exit of evaporator and condensers, power consumed by the system was recorded under the steady state operating conditions.

4. RESULTS AND DISCUSSION

The refrigerating effect of the system can be calculated as- R. E. = m C_p (t_1-t_2)
The work done by the compressor on the refrigerant is given as- W = m C_p (t_1-t_2)
The co-efficient of performance of the system is given as- COP = $\frac{R.E.}{W}$
The effectiveness of the tube in tube condenser is given as- $\varepsilon = \frac{\text{Actual heat transferred}}{\text{Maximum heat to be transferred}}$
Let, C_p = specific heat of refrigerant = 0.8035 KJ/kg K
{from – Table no. 12.1 (page no 521) in Thermal Engineering – P.L. Ballaney.**}**
m_r = mass flow rate of refrigerant in kg/min
=1.31 Kg/Min = 78.6 Kg/hr
{from – Table no. 10 (page no 309) in Refrigeration and Air Conditioning
- R.S. Khurmi and J.K. Gupta**}**

- For mass flow rate, m_w = 345 Kg/hr
- Total Consumption = 1.085 KW hr
- t_{w2} = Temperature of water at condenser in °C = 44.5°C
- t_{w1} = Temperature of water at condenser out °C = 28°C
- C_{pw} = Specific heat of water = 4.187 KJ/Kg K
- Heat gained by water,

$$Q_w = m_w\, C_{pw}\, \Delta T = 345 \times 4.187 \times (44.5\text{-}28) = 23834.498 \text{ KJ/hr} = 6.621 \text{ KW}$$

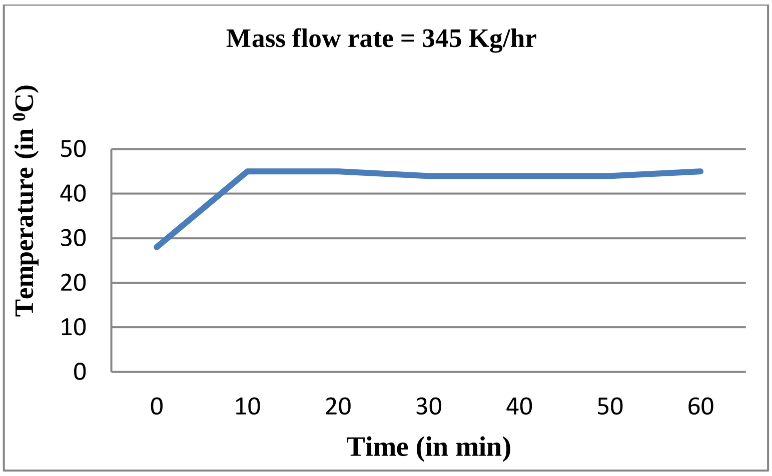


Fig 4.1: Time (in min) vs. Temperature (^{0}c) for mass flow rate of 345 kg/hr

- For mass flow rate, m_w = 305 Kg/hr
- Total Consumption = 1.175 KW hr
- t_{w2} = Temperature of water at condenser in °C = 43.5°C
- t_{w1} = Temperature of water at condenser out °C = 28°C
- C_{pw} = Specific heat of water = 4.187 KJ/Kg K
- Heat gained by water
  $Q_w = m_w\ C_{pw}\ \Delta T = 305 \times 4.187 \times (43.5-28) = 19794.04$ KJ/hr = 5.498 KW

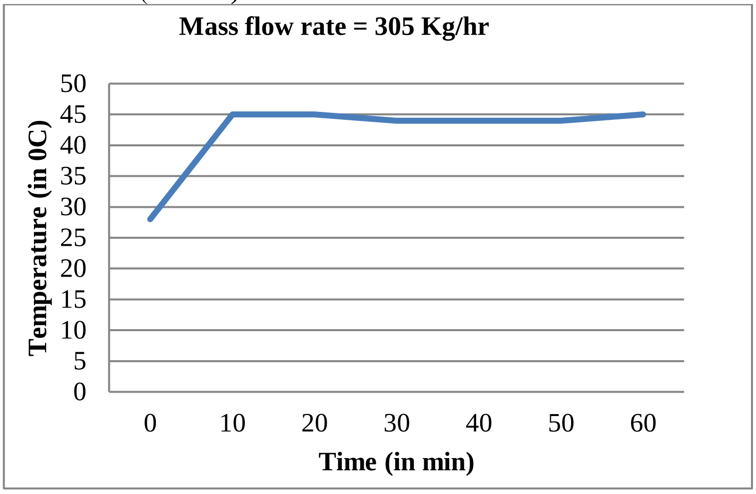


Fig 4.2: Time (in min) vs. Temperature (^{0}c) for mass flow rate of 305 kg/hr

- For mass flow rate, m_w = 260 Kg/hr
- Total Consumption = 1.239 KW hr
- t_{w2} = Temperature of water at condenser in °C = 41.83 °C
- t_{w1} = Temperature of water at condenser out °C = 29 °C
- C_{pw} = Specific heat of water = 4.187 KJ/Kg K
- Heat gained by water

$$Q_w = m_w\ C_{pw}\ \Delta T = 260 \times 4.187 \times (43.83-29) = 16144.235 \text{ KJ/hr} = 4.485 \text{ KW}$$

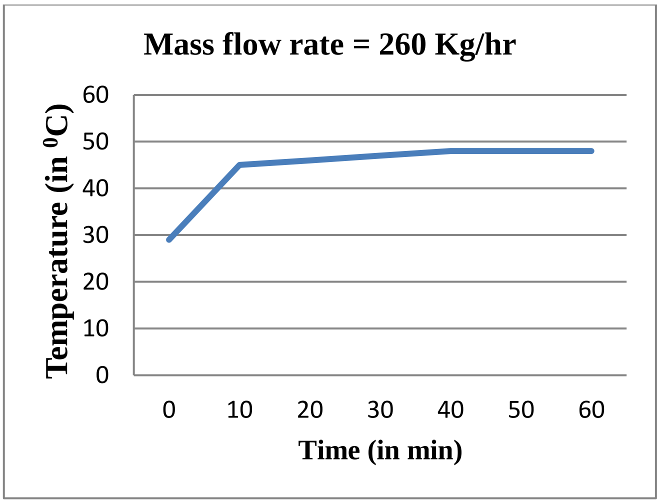


Fig 4.3: Time (in min) vs. Temperature (^{0}c) for mass flow rate of 260 kg/hr

- For mass flow rate, m_w = 200 Kg/hr
- Total Consumption = 1.309 KW hr
- t_{w2} = Temperature of water at condenser in °C = 49.67°C
- t_{w1} = Temperature of water at condenser out °C = 29°C
- C_{pw} = Specific heat of water = 4.187 KJ/Kg K
- Heat gained by water

$$Q_w = m_w\ C_{pw}\ \Delta T = 200 \times 4.187 \times (48.67-29) = 16471.658 \text{ KJ/hr} = 4.575 \text{ KW}$$

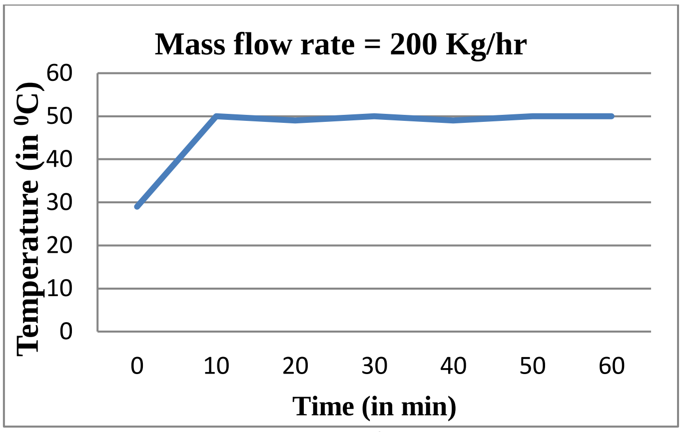


Fig 4.4: Time (in min) vs. Temperature (^{0}c) for mass flow rate of 200 kg/hr

- For mass flow rate m_w = 160 Kg/hr
- Total Consumption = 1.332 KW hr
- t_{w2} = Temperature of water at condenser in °C = 49.67 °C
- t_{w1} = Temperature of water at condenser out °C = 30 °C
- C_{pw} = Specific heat of water = 4.187 KJ/Kg K
- Heat gained by water

$$Q_w = m_w\, C_{pw}\, \Delta T = 160 \times 4.187 \times (49.67\text{-}30) = 13177.326 \text{ KJ/hr} = 3.66 \text{ KW}$$

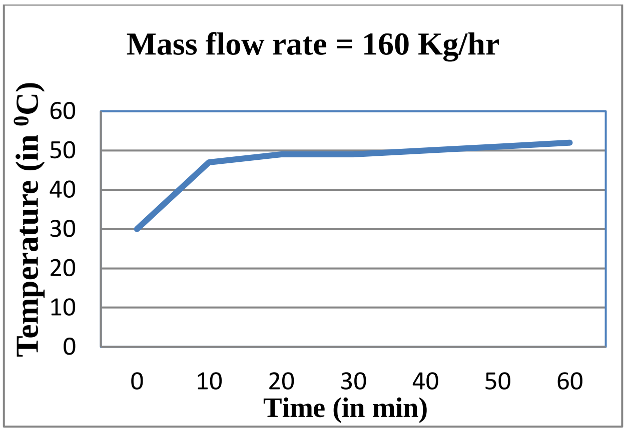


Fig 4.5: Time (in min) vs. Temperature (^{0}c) for mass flow rate of 160 kg/hr

From the p-h charts, we get-

Table 4.6: Variation of COP with mass flow rates

Reading no.	**Mass flow rate (in kg/hr)**	**$(COP)_{avg}$**
1	345	7.833
2	305	7.000
3	260	4.167
4	200	6.334
5	160	7.467

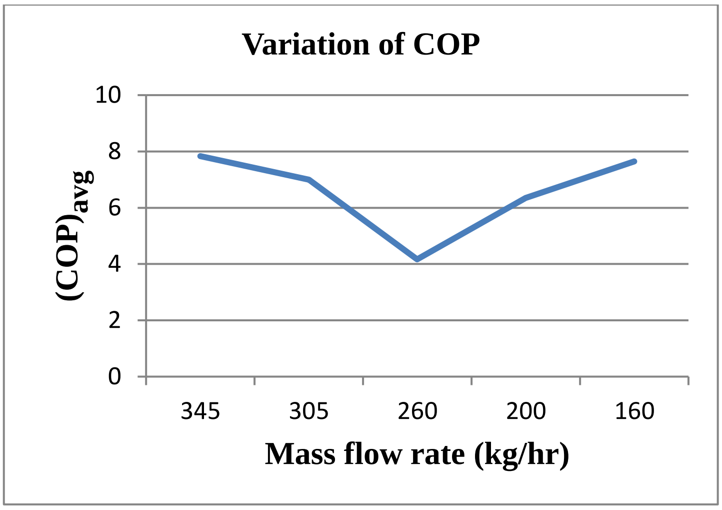


Fig 4.6: Mass flow rate (in kg/hr) vs. COP (avg)

5. CONCLUSION

- The maximum heat recovery from the water-cooled air-conditioner by using the tube-in-tube condenser occurs to be when the mass flow rate is kept high.
- The maximum heat recovery occurs to be **6.621 KW.**
- The maximum temperature of water obtained is **52 ºC.**
- The maximum COP is obtained to be **7.833** at the mass flow rate of 345 kg/hr.
- The minimum electric power consumption occurs to be **1.085 KW.hr** at water flow rate of 345 kg/hr.
- The COP of the system goes on reducing with decrease in the mass flow rate up to a particular limit and then again goes on rising.

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