Objective

- To study the coefficient of performance of an air cooler and heat pump when operating as heat pump.

Experimental Setup

The experimental setup is shown in figure (1). An air cooler and a heat pump device consist of the same components: a compressor, a condenser, an expansion valve and an evaporator. However, the desired output for both of them is different. The air cooler is used to maintain a cooled space at a low temperature, while the heat pump is used to maintain a heated space at a higher temperature. In the experiment performed in the lab, the unit was operated as a heat pump.
As shown in figure(1), the unit at the right of the figure represents the control panel. It has several switches such as : the water heater switch, the compressor switch, the fan switch and a switch to convert the device to either a heat pump or an air cooler. A wattmeter is shown also in the control panel, which displays the power consumed by the compressor and the fan when both compressor and fan switches are switched on, while it displays the power consumed by the compressor when the compressor switch only is switched on . A temperature indicator screen is found below the wattmeter screen, which displays the temperature of the fluid (refrigerant, water or air) at specific states designated by the numbers 1 – 10, depending on the position of the selector switch. Furthermore, Water is supplied and drained from the unit through two tubes connected to the backside of the unit. Water is used to evaporate the refrigerant when the device is operated as a heat pump. The mass flow rate of water is measured by a flowmeter and it is controlled by revolving the needle valve.
When operating the device as a heat pump, dry air- vapor mixture is used to condense the refrigerant . This air flows through a duct, which contains a fan that allows the air flow to occur inside the duct. The mass flow rate of the air is measured with apitot tube mounted in the center of the discharge duct. A manometer is connected to the apitot tube to measure the velocity head of the flowing air.

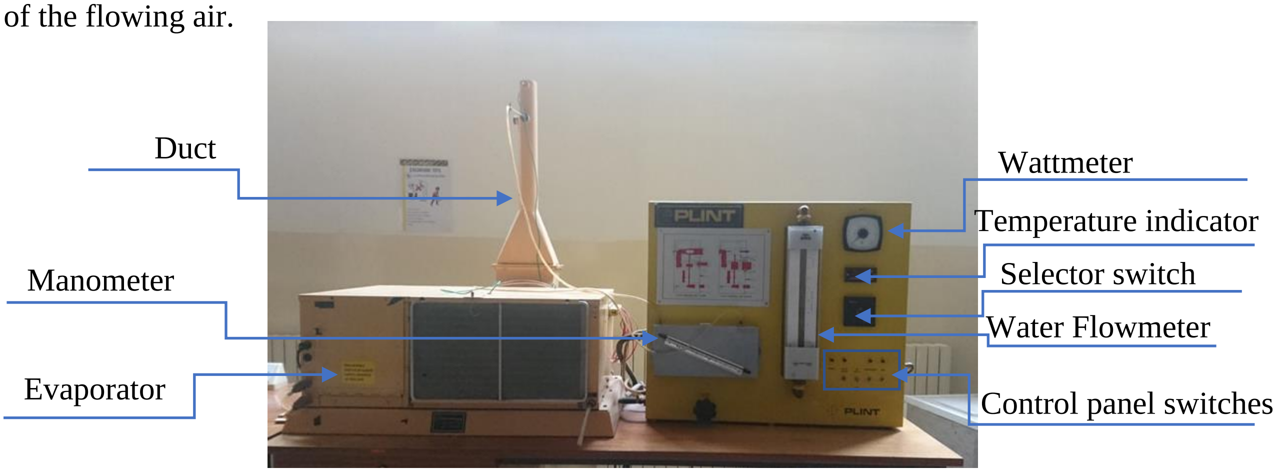

Figure (1): Air cooler & heat pump device

Start-up Procedure

1. Open the water supply valve to allow water to flow through its own pipes
2. Revolve the needle valve to set the value of mass flow rate of water in the evaporator to $\dot{m}_w = 3$ liters/min.
3. Switch on the water heater, since the device will be operated as heat pump.
4. Select heat pump option and switch on the compressor and the fan
5. The experiment now is ready to carry on.

Experimental Procedure

1. Perform the start-up procedure.
2. Wait until readings reach steady state, and then start recording the temperatures (T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}), the manometer reading, the mass flow rate of the water and the wattmeter reading, which displays the total power consumed by the compressor and the fan . Switch off the fan momentarily in order to record the power consumed by the compressor only.
3. Cover the temperature sensor in the duct with a wet wick in order to record the wet bulb temperature of the flowing air.

Given Data

- Atmospheric pressure P_{atm} = 90 kPa = 90000 N/m^2
- Atmospheric temperature T_{atm} = 19 ^oC

Data observed

Table (1) :Data Observed

Item	Symbol	Unit	Value
Air Inlet (Dry bulb Temperature)	T_1	^oC	20
Air Outlet (Dry bulb Temperature)	T_2	^oC	44
Water Inlet	T_3	^oC	19
Water Outlet	T_4	^oC	10
Compressor Outlet	T_5	^oC	77
Compressor Inlet	T_6	^oC	4
Heat Exchanger Water (Compressor End)	T_7	^oC	4
Heat Exchanger Water (Valve End)	T_8	^oC	10
Heat Exchanger Air (Compressor End)	T_9	^oC	76
Heat Exchanger Air (Valve End)	T_{10}	^oC	51
Water flow rate	$\dot{m}_w$	L/min	3
Manometer Reading	H_1	mm H_2O	34
Inlet wet bulb Temperature	$T_{i,wb}$	^oC	14
Exit wet bulb Temperature	$T_{e,wb}$	^oC	36
Compressor Power	E_c	kW	1.3
Total Electrical Power	E_T	kW	1.725

Sample Calculations

Step(1) : Find the air properties using Psychrometric Chart.

Air inlet $T_{db} = 20\ ^oC$, $T_{wb} = 14\ ^oC$

$\omega_1 = 0.0075$ kg/kg dry air , $\varphi_1 = 51\%$, h_1= 39.5 kJ/kg dry air

Air outlet $T_{db} = 44\ ^oC$, $\omega_2 = \omega_1 = 0.0075$ kg/kg dry air

$\varphi_2 = 14\%$, h_2= 65 kJ/kg dry air

Step(2) : Calculate the mass flow rate of air ($\dot{m}_a$)

$$\dot{m}_a = 0.00105 \times \sqrt{\frac{P_a \times H_a}{T_2}} \quad [1]$$

$$\dot{m}_a = 0.00105 \times \sqrt{\frac{90000 \times 34}{44+273}} = 0.1032\ kg/s$$

Step(3) : Find the heat added to the flowing air. This is a case of simple heating, in which heat is added to the air without changing its moisture. For this case :

$$\dot{Q}_H = \dot{m}_a (h_2 - h_1) \quad [1]$$

$$\dot{Q}_H = 0.1032(65 - 39.5) = 2.6316 \text{ kWatt}$$

Step(4): Find the coefficient of performance for the external cycle

$$(COP_{HP})_E = \frac{\dot{Q}_H}{E_T} \quad [1] \quad => \quad (COP_{HP})_E = \frac{2.6316}{1.725} = 1.53$$

with the maximum COP_{HP} as follows

$$(COP_{HP})_{E,max} = \frac{0.5(T_1+T_2)}{0.5[(T_1+T_2)-(T_3+T_4)]} \quad [1]$$

$$= \frac{0.5(20+273+44+273)}{0.5[(20+273+44+273)-(19+273+10+273)]} = 17.42$$

Step(4): Find the coefficient of performance for the internal cycle, by removing the effect of the fan as follows

$$(COP_{HP})_I = \frac{\dot{Q}_H - E_F}{E_c} = \frac{2.6316-0.425}{1.3} = 1.70$$

And the maximum $(COP_{HP})_{I,\max}$ is found as follows

$$(COP_{HP})_{I,\max} = \frac{T_{10}}{T_{10} - T_8} = \frac{51 + 273}{51 - 10} = 7.902$$

Uncertainty Analysis

- For a calculated quantity x that is dependent on another quantities $x_1, x_2, x_3, \ldots, x_n$
$$x = f(x_1, x_2, x_3, \ldots, x_n)$$
The uncertainty of x (w_x) is given by :
$$w_x = \pm\sqrt{\left(\frac{\partial x}{\partial x_1} \times w_{x1}\right)^2 + \left(\frac{\partial x}{\partial x_2} \times w_{x2}\right)^2 + \left(\frac{\partial x}{\partial x_3} \times w_{x3}\right)^2 + \cdots + \left(\frac{\partial x}{\partial x_n} \times w_{xn}\right)^2}$$ [2]

- In this experiment, the calculated $\dot{m}_a$ value is dependent on P_a, H_a, T_2
i.e
$$\dot{m}_a = f\ (P_a, H_a, T_2)$$
- The uncertainty of $\dot{m}_a$ is given by
$$w_{\dot{m}_a} = \pm\sqrt{\left(\frac{\partial \dot{m}_a}{\partial P_a} \times w_{P_a}\right)^2 + \left(\frac{\partial \dot{m}_a}{\partial H_a} \times w_{H_a}\right)^2 + \left(\frac{\partial \dot{m}_a}{\partial T_2} \times w_{T_2}\right)^2}$$

- The uncertainty of an observed quantity measured using a device , is the value of one-half the smallest division of the device. [2] The uncertainty P_a, H_a, T_2 of are as follows :
$$w_{P_a} = \pm\ 0.25 \text{ mbar} = \pm\ 0.025 \text{ kPa} = \pm 25\frac{N}{m^2}, \qquad w_{H_a} = \pm\ 0.25\ mm\ H_2O$$
$$w_{T_2} = \pm\ 0.5\ ℃ = \pm\ 0.5 \text{ K}$$

- The following quantities are found by differentiating $\dot{m}_a = 0.00105 \times \sqrt{\frac{P_a \times H_a}{T_2}}$ partially and plugging the values

$$\frac{\partial \dot{m}_a}{\partial P_a} = \frac{0.00105 \times \frac{H_a}{T_2}}{2\sqrt{\frac{P_a \times H_a}{T_2}}} = 5.731 \times 10^{-7}\ \frac{kg.m^2}{s.N}$$

$$\frac{\partial \dot{m}_a}{\partial H_a} = \frac{0.00105 \times \frac{P_a}{T_2}}{2\sqrt{\frac{P_a \times H_a}{T_2}}} = 1.517 \times 10^{-3}\ \frac{kg}{s.mm\ H_2O} \qquad \frac{\partial \dot{m}_a}{\partial T_2} = \frac{0.00105 \times \frac{-P_a \times H_a}{T_2^2}}{2\sqrt{\frac{P_a \times H_a}{T_2}}} = -1.627 \times 10^{-4}\ \frac{kg}{s.K}$$

$$w_{\dot{m}_a} = \pm\sqrt{(5.731 \times 10^{-7} \times 25)^2 + (1.517 \times 10^{-3} \times 0.25)^2 + (-1.627 \times 10^{-4} \times 0.5)^2}$$
$$= \pm 3.88 \times 10^{-4} \text{ kg/s} = \pm 0.376\ \%$$

Results & Discussion

An air compressor is a mechanical device that increases the pressure of air by reducing its volume. Since the objective of this experiment is to study the performance of a single stage air compressor, several conclusions can be drawn from the results obtained from calculations. Firstly, the volumetric efficiency of the compressor is η_{vol} = 66.02%. This value means, that only 0.6602 of the volume of the cylinder was filled with air during the air suction process. Secondly, the mechanical efficiency of the compressor is η_{mech} = 49.24%. This value means that 0.4924 of the power supplied to the compressor is used to compress the air and increase its pressure. Heat and frictional losses dissipates the rest of the power supplied to the compressor. Thirdly, the isothermal efficiency of the compressor η_{isoth} = 64.22%. This value represents the ratio of the work required to compress a gas isothermally to the work actually done by the compressor. This means that the compression process is not absolutely an isothermal process . Furthermore, the motor efficiency η_{motor} = 11.31% . This means that 88.69% o f the power supplied to the motor was dissipated due to frictional and heat losses. Finally, the overall efficiency $\eta_{overall}$ indicates that only 5.45% of the power supplied to the unit was used to compress the air and increase its pressure.

Sources of Error

Errors in this experiment are caused by several factors such as: human error in recording the experimental data of the motor current, motor voltage, pressure gauge and the dynamometer force, since these data are not recorded digitally like the rotational speed of the motor and the values of temperature. In addition, computational errors are also considered as a source of error.

Summery & Conclusions

Overall, the experiment shows that compressors are devices that increase the pressure of a gas by reducing its volume. Frictional and heat losses dissipate most of the power supplied to the compressor, which causes a reduction in the mechanical, isothermal and overall efficiencies of the compressor.

References

[1] Çengel, Y. A., & Boles, M. A. (2015). Thermodynamics: an engineering approach (8th ed.). New York: McGraw-Hill Education.

[2] Chapra, S. C., & Canale, R. P. (2010). Numerical Methods for Engineers (6th ed.). New York: McGraw-Hill Education.

[3] Holman J. P. (2012). Experimental Methods for Engineers (8th ed.). New York: McGraw-Hill Education.