

# Water Cooled Condenser Using Nano Fluids

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## Abstract

Water cooler is one of the familiar appliances utilizing vapour compression cycle in its process. Performance of the system becomes main issue and many researches are still on going to evaluate and improve efficiency of the system. The main objective is to improve performance of the refrigeration system in term of Compressor work and Coefficient of performance (COP) by determining three important parameters during in operating mode which are temperature, pressure and refrigerant flow rate. We are going to introduce the water cooled condenser along with CuO Nano particles in a model of domestic water cooler for cooling the refrigerant and the effect of condenser temperature on COP and refrigerating effect is in investigated. The energy consumption of the water cooler during experiment with refrigerant R134a will be measured.

Nano fluid is an advanced kind of fluid, which contains nanometer, sized solid particles that are known as nanoparticles. Nanoparticles enhance the property of normal fluid. In the conventional water cooler, condenser heat loss via conduction-radiation (copper tube-atmosphere). In our research work, we are trying to increase heat loss in condenser with some additional device attachment (copper tube flow with Nano fluid). With the help of our arrangement heat loss increases via conduction-convection-radiation. So our arrangement increasing heat loss and our goal is achieve. With this setup we are increasing COP of water cooler using water cooled condenser along with Nano particles.

**Key words:** Water Cooled Condenser, Tube in tube type condenser, Refrigerant R134-A, Coefficient of performance, Nano fluid- CuO

## Introduction

Energy is an important entity for the economic development of any country. The rapid industrial and economic growths in India and China where one third population of the world live, have increased the need of energy rapidly in the recent years. Considering the environmental protection and also in the context of great uncertainty over future energy supplies, attention is concentrated on the utilization of sustainable sources and the energy conservation methodologies.

Today world's 15% of total electrical energy is used

for refrigerating and air conditioning applications (As per US Department of energy). In refrigeration and air conditioning systems, the compressor is the largest consumer of electricity, in most of the cases consuming about 70% of total electricity. Refrigeration and air conditioning systems tend to underperform in extremely hot climatic conditions as prevailed in South-East-Asian nations. Generally an air cooled condenser is employed to reject heat from conditioned space to outdoors. The reason being to make the system as simple as possible without any need to the water connection line and other equipment's. This idea seems quite reasonable as far as the air temperature in summer is moderate and not too high, say about 35-37 °C. However, summer temperature in South-East-Asian often exceeds this range.

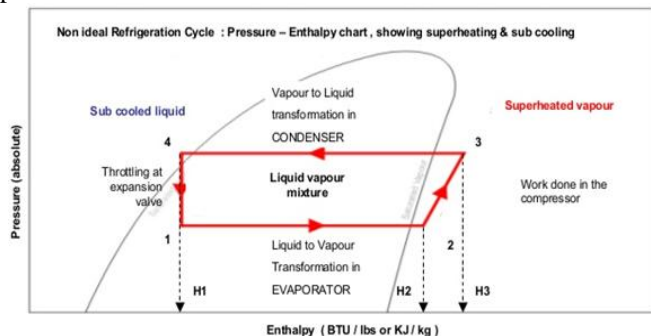
Temperature of air-cooled condenser directly depends on the ambient air temperature. Therefore, in area with very hot weather temperature in summer; the condenser temperature and pressure are increased considerably which consequently increases the power consumption of the refrigeration system due to increase in the pressure ratio. Increasing condenser temperature also decreases cooling capacity of the cycle due to the reduction of liquid content in the evaporator. This two effect decrease performance of the system considerably in the area with very hot weather temperatures prevailing summer. Thus, water cooler turns out to be the major contributors to the summer peak electrical demands in most of the nations. Therefore, it is important to have a refrigeration system which can decrease the energy demands and also improve the C.O.P.

## Compressor Power

As mentioned above compressor is the main consumer of electricity in refrigeration and air conditioning systems. Hence to have an energy efficient system we need to reduce compressor power. One of the factor on which compressor power depends is the temperature of heat rejection at the condenser. If the temperature of heat rejection at condenser is high, correspondingly compressor consumes relatively more power in order to bring refrigerant temperature higher than that of cooling medium temperature. It is always beneficial in terms of energy conservation to reduce temperature of heat rejection by employing proper method of heat rejection at condenser side.

A lot depends on condenser design or its operating temperature and pressure. Either the condenser needs to be redesigned, altering its length and/or diameter or by adopting techniques like internal grooving, optimizing external fins, fin length, fin spacing etc. or the other option is to reduce the operating temperature and pressure of existing condenser design by some means.

The p-h chart as seen in fig. shows that, if the condenser temperature and pressure is reduced, the compressor work is reduced whereas the refrigeration effect is increased. This indicates that by improving the condenser cooling to reduce its temperature and pressure, the system performance can be enhanced.



**Fig. 1** Chart showing effects of condenser temperature and pressure

### Methodology

In hot climatic countries especially in South-East-Asian countries, due to hot climatic conditions throughout the year, need of cold water for drinking always prevails. This increases use of the water cooler. Conventional water cooler operates on vapor compression system where air is used as cooling medium at the condenser. Air is available at an atmospheric temperature and hence compressor has to compress the refrigerant to temperature higher than atmospheric temperature. Consequently there is increase in the ambient temperature and performance of the water cooler reduces due to under-cooling of the condenser.

The one way to reduce the compressor work is to decrease the condenser pressure which needs to decrease the condenser heat rejection temperature. To reduce heat rejection temperature at the condenser, an alternate cooling medium instead of air can be used, and water along with Nano fluid could be an alternate cooling medium which is available at lower. Further, availability of water is also easy for cooler as it has already sustained water connection and always near water source.

### Water Cooled Condenser

Water is another cooling medium which is easily available and is at much lower temperature than atmospheric air. Water is more preferable as cooling medium rather than the air because of following reasons:

- It is available at temperature lower than that of air. Its temperature approaches to the wet bulb temperature of the surrounding air.
- The specific heat of water is about four times that of air. Hence for the same heat rejection and same mass flow, the temperature rise of water is one-fourth that

of air and correspondingly temperature of heat rejection is lower.

- Water has higher heat transfer coefficient than the air mainly because of its high thermal conductivity. Thus for the same heat rejection and same area of heat exchanger, the temperature difference required across the heat exchanger is less which also results in lower value of temperature of heat rejection.

Hence the use of water as cooling medium results in lower heat rejection temperature at condenser, which will decrease the compressor power and hence COP will also improve.

All this will result into energy efficient system. Using water as cooling medium there will be more compact and smaller condenser even with the smaller value of mean temperature difference. Therefore to decrease the energy consumption and to have a better performance of the water cooler use to water as cooling medium at the condenser side can be good option.

Water cooled condenser system can be of two types viz. open cooling water cooled condenser and another is closed cooling water cooled condenser. In the open cooling water cooled condenser system the water is directly sprinkled or made to flow over the condenser tube. This cooling system is similar to the cooling tower. This cooling system requires pumping system to sprinkle water over condenser tube and the collecting system to collect the water sprinkled over condenser tubes. In this closed cooling water cooled condenser system generally we use the heat exchanger to exchange the heat between the cooling water and the condenser.

Internal water cooling system is more preferred over external due to following advantages,

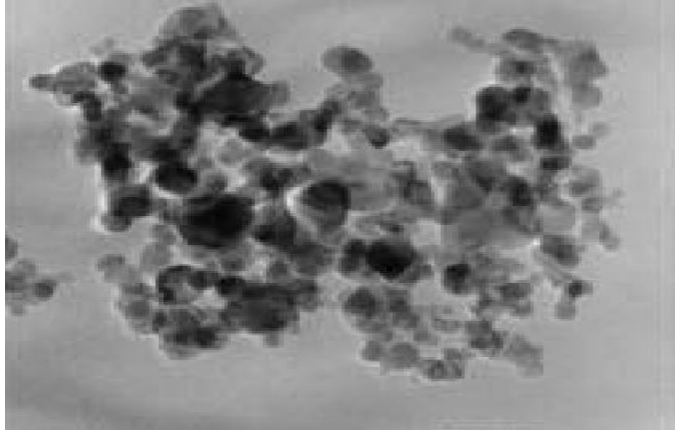
- It improves flexibility in site location problems. Generally external cooling water cooled condenser systems must be installed above the heat source and the internal cooling system can be placed anywhere.
- Generally we can maintain the high pressure of the cooling medium in the internal cooling water cooled condenser system, which leads to better cooling in short period of time.
- External cooling water cooled condenser system requires more space compared to the internal cooling water cooled condenser system.
- Internal cooling water system is more compact than the open cooling water cooled condenser system.

Hence external cooling water cooled condenser system is a better option

### Nano Fluid

A Nanofluid is a mixture of water and suspended metallic nanoparticles. Since the thermal conductivity of metallic solids are typically orders of magnitude higher than that of fluids it is expected that a solid/fluid mixture will have higher effective thermal conductivity compared to the base fluid. Thus, the presence of the nanoparticles changes the transport properties of the base fluid thereby increasing the

effective thermal conductivity and heat capacity, which ultimately enhance the heat transfer rate of Nano fluids. Because of the small size of the nanoparticles (10-9 m), Nano fluids incur little or no penalty in pressure drop and other flow characteristics when used in low concentrations. Nano fluids are extremely stable and exhibit no significant settling under static conditions, even after weeks or months. In their work (Lee & Choi) on the application of Nano fluids reported significant cooling enhancement without clogging the micro-channels.



**Fig. 2** Copper Oxide

Nanoparticles are very small nanometre sized particles with dimensions 0.1-1000 nm (nanometres) in size. Some of the common oxide nanoparticles being used in heat transfer research are: Zinc Oxide (ZnO), Zirconia (ZrO<sub>2</sub>), Copper Oxide (CuO), Aluminium Oxide (Al<sub>2</sub>O<sub>3</sub>), and Titanium Oxide (TiO<sub>2</sub>) while some of the metal nanoparticles are Gold (Au), Silver (Ag), and Copper (Cu). Conventional fluids being mixed with nanoparticles are: water, ethylene glycol, and oil.

Water is a convenient and safe medium; however, it has poor heat transfer characteristics which are a major disadvantage. For example, water is roughly three orders of magnitude poorer in heat conduction than copper; as is the case with coolants such as engine coolants, lubricants, and organic coolants. The use of Nano fluids (nanoparticles + conventional fluids), like water, may possess the ability to increase the convection heat transfer characteristics of that particular fluid.

### Refrigerant

The suitability of refrigerant for a certain application is determined by its physical, thermodynamic, chemical properties and by various practical factors. There is no one refrigerant which can be used for all types of applications i.e. there is no ideal refrigerant. If one refrigerant is chosen which has greater advantages and less disadvantages.

So, we have used refrigerant R-134a.

### Design of Water Cooled Condenser

Many commercial design and types of heat exchangers are available in market.

Selection of the type of heat exchanger for the given application is based on following considerations/constraints:

- Compactness of the heat exchanger

- Minimum cost
- Minimum disturbance to the existing process line due to this new installation
- Applications
- Space requirement

Depending on the temperature of the heat rejection at condenser, a suitable heat exchanger is to be selected that facilitates heat exchanger. Heat exchangers such as shell and tube, plate and fin type, double pipe, etc. are available. It is desirable to have compact, cost effective and better performance heat exchanger. Shell and tube heat exchanger being neither compact nor cost effective, was not considered. Further, plate fin type heat exchanger is best both performance wise and compactness wise, but high cost of it does not make it suitable for our application. Double pipe heat exchanger is compact one and cost effective, therefore it can be better option for our application. Hence it is decided to replace existing air cooled condenser by double pipe water cooled condenser with the arrangement to use the waste water of cooler.

Thermal design of the heat exchanger is carried out on the following considerations:

- Flow rates of both fluids; inlet temperature of cooling water, power consumed by compressor, cooling capacity, mass of water to be cooled, velocity of cooling water are required.
- Fouling resistance for both streams are to be furnished, the designer should adopt values specified in the standards or based on past experience.
- Physical and thermal properties of both streams include velocity, thermal conductivity, density, specific heat and Prandtl number, preferably at both inlet and outlet temperatures. Velocity data must be supplied at inlet and outlet temperatures, especially for liquids, since the variation with temperature may be considerable and is irregular.
- Condenser line sizes are desirable to much nozzle sizes with existing line sizes to avoid expanders or reducers.
- Preferred tube sizes are designated as I.D., O.D., thickness and length. Some plant owners have proffered I.D., O.D., thickness and the available plot area will determine the maximum tube length. Many plant owners prefer to standardize all four dimensions, again based upon inventory considerations.
- Materials of construction, for maximum heat transfer on refrigerant side copper issued and for outer side cast steel is used.

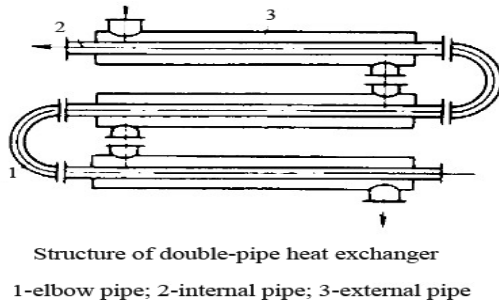
### Design Methodology

Heat exchanger is designed for water cooler having following specifications:

- Made – ST 4-80
- Power consumption – 575
- Refrigerant – R-134a, 375gm
- Storage tank – 80 liters
- Cooling capacity – 40 liters/hour

- Compressor – KCE 443 HAE

Cooling water at temperature  $tcw1$  enters outer pipe of double pipe condenser and leaves the condenser at temperature  $tcw2$  as shown in Fig. 3. At the same time refrigerant enters the inner tube of double pipe condenser in at temperature  $t_{sup}$  1 and leaves the condenser at temperature  $t4$ .



Structure of double-pipe heat exchanger

1-elbow pipe; 2-internal pipe; 3-external pipe

Fig. 3. Double pipe heat exchanger

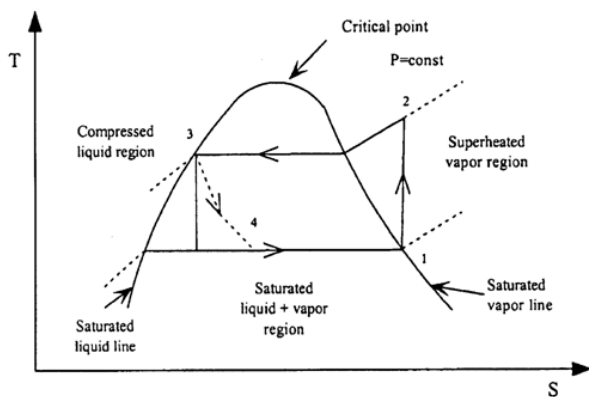


Fig.4. Refrigeration cycle on T-S diagram

Fig. 4 shows refrigeration cycle on T-S diagram. The refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. Here, it is assumed that refrigerant leaves the condenser as a sub cooled liquid. The heat rejection process is represented by 2-3'-3-4. The temperature profile of the water, which is assumed to undergo only sensible heat transfer, is shown by dashed line. It can be seen that process 2-3' is a de-superheating process, during which the refrigerant is cooled sensibly from a temperature  $T2$  to the saturation temperature corresponding condensing pressure,  $T3$ . Process 3'-3 is the condensation process, during which the temperature of the refrigerant remains constant as it undergoes a phase change process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from  $T3$  to  $T4$ . It is also assumed that during evaporation process refrigerant gets superheated and enters the compressor in the superheated state.

During its path through condenser, the refrigerant coexists in three phases. Refrigerant enters a gaseous state, goes through a two-phase state and finally leaves the condenser in a liquid state as shown in fig 4.3. Generally during designing of condenser or modeling, three zones are considered as one lumped two-phase zone, where only one

global heat transfer coefficient is calculated or identified as we have done above in our designing. But we have to consider a more detailed model which distinguish between the different zones and identifies a specific heat transfer coefficient for each zone. This approach allows us to verify the separate influences of gaseous, two-phase and liquid zones on the heat exchanger performance.

### Set up Diagram

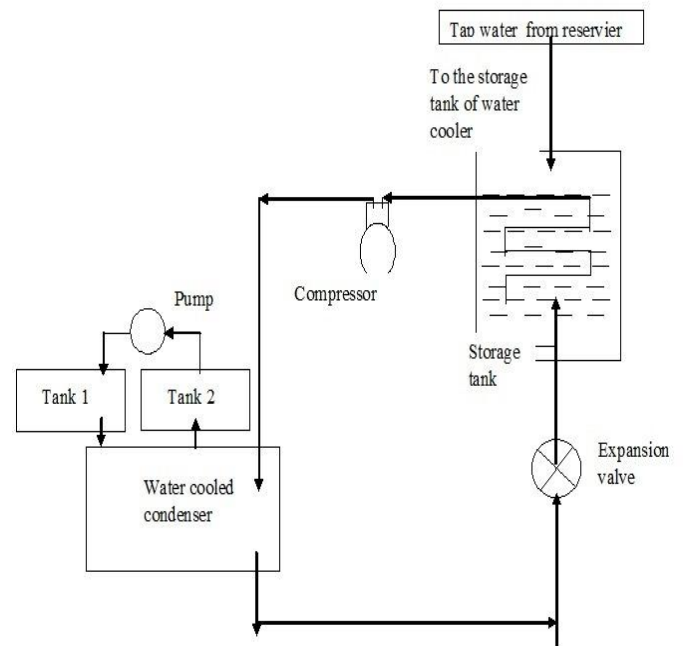


Fig.5. Schematic diagram of modified water cooler with water cooled condenser

### Calculations

Cooling capacity of system in KW is given by,

$$Q_{cooling\ capacity} = \dot{m}_w \cdot C_{p,w} \cdot \Delta T$$

$$= \frac{40}{3600} * 4.186 * (28 - 16)$$

$$= 0.5581 \text{ kW}$$

By using cooling capacity and the power consumed calculate the total amount of heat rejected by using First law of Thermodynamics as,

$$Q_{rej} = Q_{cooling\ capacity} + \{ \text{Input Power} \}$$

$$= 0.5581 + \{0.45\}$$

$$= 1.0081 \text{ kW}$$

Assuming temperature of heat rejection at condenser, temperature at evaporator and the temperature of sub-cooling; calculated the temperatures at entry and exit of the compressor and from that calculate enthalpies at entries and exists of compressor, condenser and evaporator.

Assumed temperature:-

$T1 = 10.8^\circ\text{C}$	$h1 = 424 \text{ kJ/Kg}$
$T2 = 24.5^\circ\text{C}$	$P1 = 2.41 \text{ bar}$
$T3 = 80.4^\circ\text{C}$	$h2 = 468 \text{ kJ/Kg}$
$T4 = 41.8^\circ\text{C}$	$P2 = 10.81 \text{ bar}$
$T5 = 16^\circ\text{C}$	$h3 = 260 \text{ kJ/Kg}$
	$h4 = 260 \text{ kJ/Kg}$

NOTE – Enthalpy values are taken from p-h chart of “R-134a” at desired pressure.

Calculating refrigerating effect

$$Re = h_1 - h_4$$

$$= (424 - 260)$$

$$Re = 164 \text{ KJ/Kg}$$

Calculate mass flow of refrigerant

$$Mr = \frac{Q_{\text{cooling capacity}}}{RE}$$

$$= \frac{0.5581}{164}$$

$$= 0.0033 \text{ Kg/s}$$

By using heat balance equation at condenser side we will calculate exit temperature of the cooling water as,

Assume  $T_{cw2} = 26^\circ\text{C}$

$$M_{cw} \cdot C_p \cdot C_w (t_{cw2} - t_{cw1}) = Mr (h_2 - h_4)$$

$$M_{cw} \cdot 4.186 \cdot (30 - 26) = 0.0033(468 - 260)$$

$$M_{cw} = 0.0409 \text{ Kg/s}$$

Volume flow rate of cooling water

$$M_{cw} = (\rho_{cw}) \cdot (Vol_{cw})$$

$$0.0409 = (1000) \cdot (Vol_{cw})$$

$$Vol_{CW} = 4.09 \cdot 10^{-5} \text{ m}^3/\text{sec}$$

Calculate the Velocity of cooling water

$$Vol_{CW} = \frac{((3.14) \cdot (Di)^2 - (do)^2) \cdot V_{cw}}{4}$$

$$4.09 \cdot 10^{-5} = \frac{((3.14) \cdot (0.025)^2 - (0.006)^2) \cdot V_{cw}}{4}$$

$$V_{cw} = 0.08845 \text{ m/s}$$

Assume,

Temperature of cooling water inlet to condenser =  $26^\circ\text{C}$

Temperature of cooling water exit to condenser =  $30^\circ\text{C}$

$$\text{Mean value} = \frac{26+30}{2}$$

$$= 28^\circ\text{C}$$

Values for temperature  $28^\circ\text{C}$  (for cooling water)

Viscosity ( $\mu$ ) =  $0.83 \times 10^{-3} \text{ Kg/m-s}$

Density ( $\rho$ ) =  $99.4 \text{ Kg/m}^3$

Thermal conductivity ( $K_r$ ) =  $0.611 \text{ w/m-k}$

Specific heat ( $C_p$ ) =  $4178.8 \text{ J/Kg-K}$

Prandlt no. ( $Pr$ ) =  $5.708$

For liquid phase (for refrigerant R-134a) at temp.  $= \frac{81.4+41}{2} = 61.2^\circ\text{C}$

Viscosity ( $\mu$ ) =  $1.239 \times 10^{-4} \text{ Kg/m-s}$

Density ( $\rho$ ) =  $1220 \text{ Kg/m}^3$

Thermal conductivity ( $K_r$ ) =  $0.0640 \text{ w/m-k}$

Specific heat ( $C_p$ ) =  $1672.86 \text{ J/Kg-K}$

Prandlt no. ( $Pr$ ) =  $3.234$

Liquid Reynold's no.

$$Re_L = \frac{\rho V D}{\mu}$$

$$= \frac{99.4 \cdot 0.088 \cdot 0.025}{0.83 \times 10^{-3}}$$

$$Re_L = 2650.60$$

Nussle no.

$$Nu = 0.023 \cdot Re^{0.2} \cdot Pr^{0.3}$$

$$= 0.023 \cdot (2650.6)^{0.2} \cdot (5.708)^{0.3}$$

$$= 1.946$$

$$ho = \frac{Nu \cdot Kr}{L_c}$$

$$= \frac{1.946 \cdot 0.611}{0.00624}$$

$$= 190.54 \text{ W/m}^2\text{C}$$

Vapor Reynold's no.

$$Re_v = \frac{\rho V D}{\mu}$$

$$= \frac{1220 \cdot 0.04 \cdot 0.006}{1.239 \times 10^{-4}}$$

$$Re_L = 2363.19$$

Nussle no.

$$Nu = 0.023 \cdot Re^{0.2} \cdot Pr^{0.3}$$

$$= 0.023 \cdot (2363.19)^{0.2} \cdot (3.234)^{0.3}$$

$$= 2.72$$

$$hi = \frac{Nu \cdot Kr}{L_c}$$

$$= \frac{2.72 \cdot 0.0640}{0.00149}$$

$$= 117.02 \text{ W/m}^2\text{C}$$

Calculate the log mean temperature difference (LMTD)

$$LMTD = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1 / \Delta T_2)}$$

For parallel flow

$$\Delta T_1 = Th_1 - Tc_1$$

$$= 81.4 - 26$$

$$= 55.4^\circ\text{C}$$

$$\Delta T_2 = Th_2 - Tc_2$$

$$= 41 - 30$$

$$= 11^\circ\text{C}$$

$$\text{By LMTD --- } LMTD = \frac{(55.4 - 11)}{\ln(55.4/11)}$$

$$= 27.46$$

Overall heat transfer coefficient ( $U_o$ )

$$U_o = \frac{1}{\frac{1}{hi} + \frac{1}{ho}}$$

$$= \frac{1}{\frac{1}{117.02} + \frac{1}{190.54}}$$

$$= 72.50 \text{ W/mK}$$

$$U_o = 72.50 \times 10^{-3} \text{ kW/mK}$$

LENGTH OF CONDENSER ( $L$ ) =

$$Q = U_o \cdot A \cdot \Delta T_m$$

$$Q = U_o (3.14 \cdot D \cdot L) \cdot (\Delta T_1 - \Delta T_2)$$

$$1.0081 = 72.50 \cdot 10^{-3} \cdot 3.14 \cdot 0.025 \cdot L \cdot 27.46$$

$$L = 6.45 \text{ m}$$

Observations for water cooler with Nano fluid (CuO + water) cooled condenser

Sr. No.	Pressure (in psi)		Condenser temperature (in °C)		Evaporator temperature (in °C)		Time required for 10 rev. of energy meter	Drinking Water Temperature (in °C)
	Discharge pressure	Suction Pressure	inlet	outlet	inlet	outlet		
1	125	35	52.5	27.7	8.8	15.1	24.9	16
2	125	37	61.0	31.5	10.2	7.9	24.3	15

