# CHAPTER 3 EXPERIMENTAL APPARATUS

A schematic diagram of the test apparatus is shown in Fig. 3.1. The refrigerant loop consists of a pre-heating loop, test section, heating/cooling loop, and chilling loop. The refrigerant loop does not use a compressor. Instead, a gear pump is used to circulate the refrigerant. The gear pump has the advantage over other pumps in that it does not require a lubricant during operation. An inverter controls the pump speed. A refrigerant filter and dryer removes any water vapor or particulate matter, which may harm the pump and flow meter.

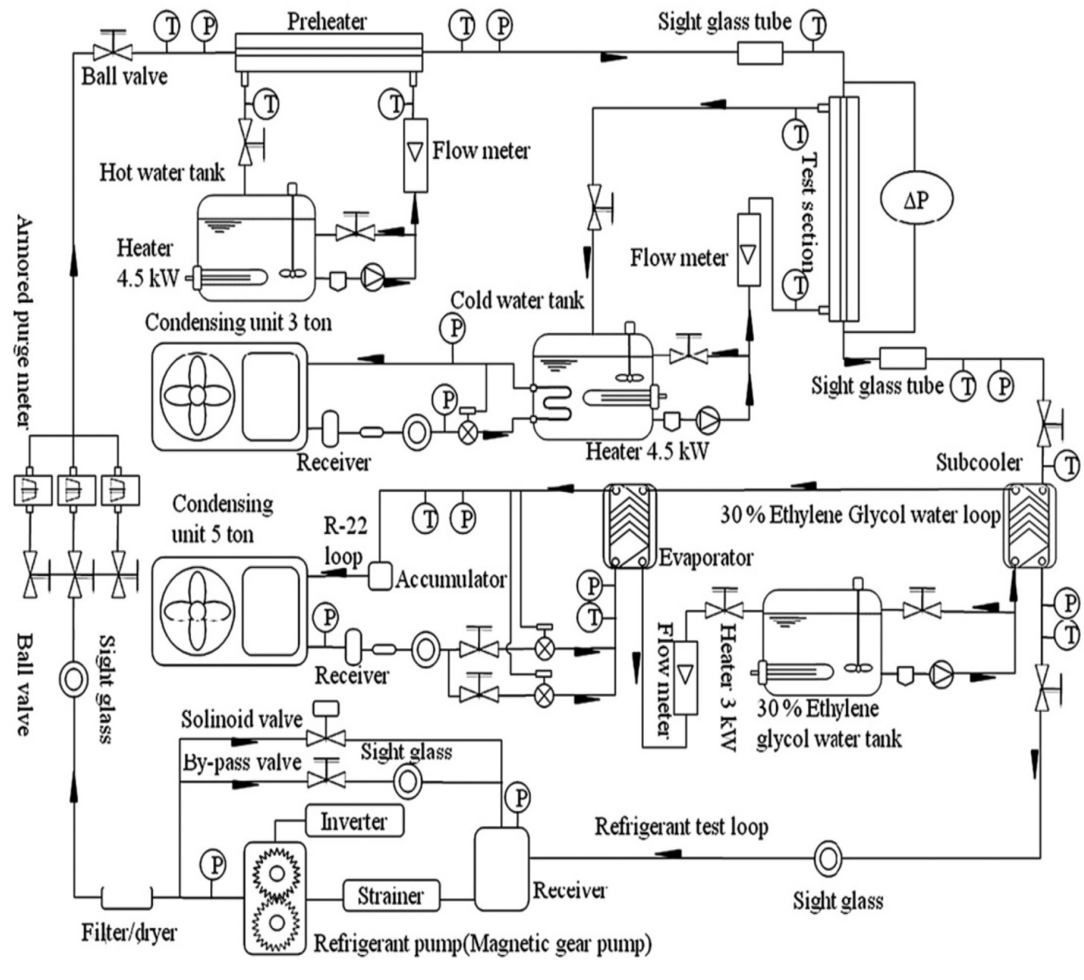


**Figure 3.1** Schematic diagram of the experimental apparatus.

### 3.1 Refrigerant Loop

The refrigerant exiting the test section is condensed and sub-cooled in the chilling loop. The sub-cooled refrigerant is then circulated with the gear pump. The flow rate of refrigerant in the test section is controlled with a by-pass line and the pump speed. Prior to entering the test section, the refrigerant is heated to the proper temperature and quality of vapor in the pre-heater located directly upstream of the test section. Sight glasses for the observation of flow patterns are located at the entrance and exit of the test tube.

### 3.2 Preheating Loop

The preheating loop supplies energy for the vaporization of the refrigerant. The main components of the preheating loop are a centrifugal pump, a water tank, a heater and a flow meter. The centrifugal pump circulates the water through the loop and controls the flow rate by using by-pass valves and an inverter. The thermocouples (type-T) are used to measure the water temperature at the inlet and outlet of the preheating loop.

### 3.3 Heating/Cooling Loop

The heating/cooling loop circulates water through the annulus of the test section heat exchanger. The heating/cooling water loop contains a reservoir, a pump, a cooler, and a flow meter. The temperature of the water entering the annulus of the heat exchanger is controlled with the cooler. The flow meter is used to measure the water flow rate. A centrifugal pump circulates the water from the tank to the test section.

### 3.4 Chilling Loop

The chilling loop is designed to remove the heat input from the pre-heater and test section and return the two-phase refrigerant to a sub-cooled state. It is a cascading system composed of an ethylene glycol-water loop and R-22 refrigeration system. After the refrigerant leaves the test section, it moves into the plate heat exchanger. The working fluid in the heat exchanger is a 30% ethylene glycol-water solution. The purpose of the R-22 refrigerant system is to absorb heat from the ethylene glycol-water loop and reject it to the surroundings.

### 3.5 Test Section

Details of the test section are shown schematically in Fig. 3.2. The test section is a vertical counter-flow double tube heat exchanger with refrigerant flowing downward in the inner tube and water flowing upward in the annulus. The test sections are one smooth tube and five corrugated tubes, which are made from copper. The inner diameter and outer diameter of the inner tube are 8.7 and 9.52 mm, respectively. The length of the test section is 500 mm. Fig. 3.3 shows the sketch and the actual photograph of corrugated tube. The dimensions of the test section are listed in Table 3.1. T-type thermocouples are installed at the inlet and outlet of the test section to measure the saturation temperature of the refrigerant. Similarly, the differential pressure transducer is installed in order to measure the pressure drop across the test section. The length between the pressure taps is 850 mm. There are 10 thermocouples located at five positions along the test section. All of the wall thermocouples are fixed with special glue having low thermal conductivity. The test section is insulated with rubber foam with a thermal conductivity of 0.04 W/mK. All of the thermocouples are well calibrated by standard thermometers with a precision of 0.1°C. The refrigerant flow meter is a variable area type and is specially calibrated in the range of 0.2–3.4 L/min for R-134a by the manufacturer, and so is the differential pressure transducer. In the experiments, the inlet quality of the test section is varied by small increments. The imposed heat flux, mass flux, and saturation temperature are kept constant at the desired values. The system is allowed to approach a steady state before any data are recorded. During experiments, the temperature and pressure are continuously recorded along the test section by the data acquisition system. The range of experimental conditions tested in this study is listed in Table 3.2. The uncertainties of measured quantities and calculated parameters, which are calculated from the root mean sum square method, are shown in Table 3.3.

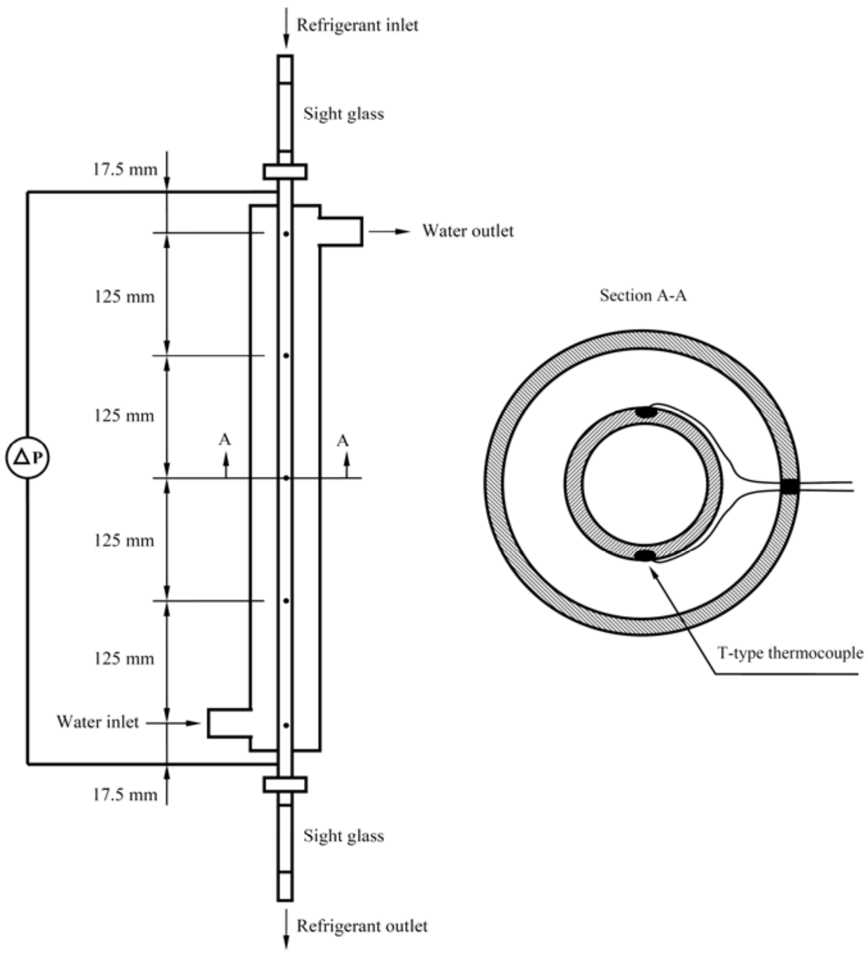


**Figure 3.2** Schematic diagram of the test section.

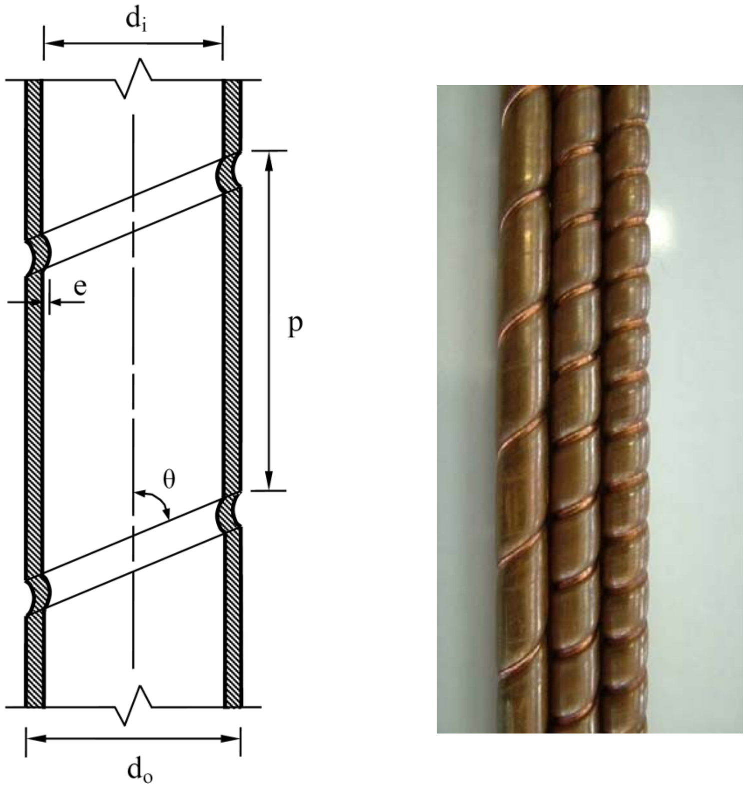


**Figure 3.3** (a) Sketch and (b) actual photograph of the corrugated tube.

**Table 3.1** The dimensions of the test sections.

| **Parameters** | **Smooth tube** | **Corrugated tube** | | | | |
|---|---|---|---|---|---|---|
| Outer diameter, mm | 9.52 | 9.52 | 9.52 | 9.52 | 9.52 | 9.52 |
| Inner diameter, mm | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 |
| Length of test section, mm | 500 | 500 | 500 | 500 | 500 | 500 |
| Inside tube area, $mm^2$ | 13665.9 | 14514 | 14938 | 15362.2 | 15951.1 | 16582.8 |
| Pitch of corrugation, mm | - | 12.7 | 12.7 | 12.7 | 8.46 | 6.35 |
| Depth of corrugation, mm | - | 0.5 | 0.75 | 1 | 1 | 1 |
| Helix angle, deg | - | 53.875 | 53.875 | 53.875 | 64.07 | 69.95 |

**Table 3.2** Experimental conditions.

| **Controlled variable** | **Evaporation** | **Condensation** |
|---|---|---|
| Mass flux ($kg/m^2s$) | 200, 300, 400 | 300, 400, 500 |
| Heat flux ($kW/m^2$) | 20, 25, 30 | 20, 25, 30 |
| Saturation temperature (ºC) | 10, 15, 20 | 40, 45, 50 |
| Tested tube material | copper | copper |
| Refrigerant | R-134a | R-134a |

**Table 3.3** Uncertainties of measured quantities and calculated parameters.

| **Parameter** | **Uncertainty** |
|---|---|
| Temperature, T | ± 0.1 |
| Frictional pressure drop, $\Delta P_F$ | ± 10 % |
| Mass flow rate of refrigerant, $m_{ref}$ | ± 2% Full scale |
| Heat transfer rate of test section, $Q_{TS}$ | ± 15 % |
| Heat transfer rate of pre-heater, $Q_{ph}$ | ± 10 % |
| Average heat transfer coefficient, $h_{avg}$ | ± 15 % |
| Two-phase friction factor, $f_{tp}$ | ± 13 % |
| Average quality, $x_{avg}$ | ± 8 % |
| Equivalent Reynolds number, $Re_{eq}$ | ± 6 % |