CHAPTER 3

EXPERIMENTAL STEAM JET REFRIGERATOR

To investigate the actual performance of a steam jet refrigeration, an experimental jet refrigerator was designed and tested. The experimental refrigerator was designed to produce 1 kW of cooling. Electrical heaters were used as the heat source for the boiler and the cooling load for the evaporator.

3.1 The experimental refrigerator

In this study, the experimental refrigerator used was designed and constructed previously by, Chunnanond et al. [3]. The schematic diagram and photograph of the experimental refrigerator are shown in figure 3.1 and figure 3.2 respectively.

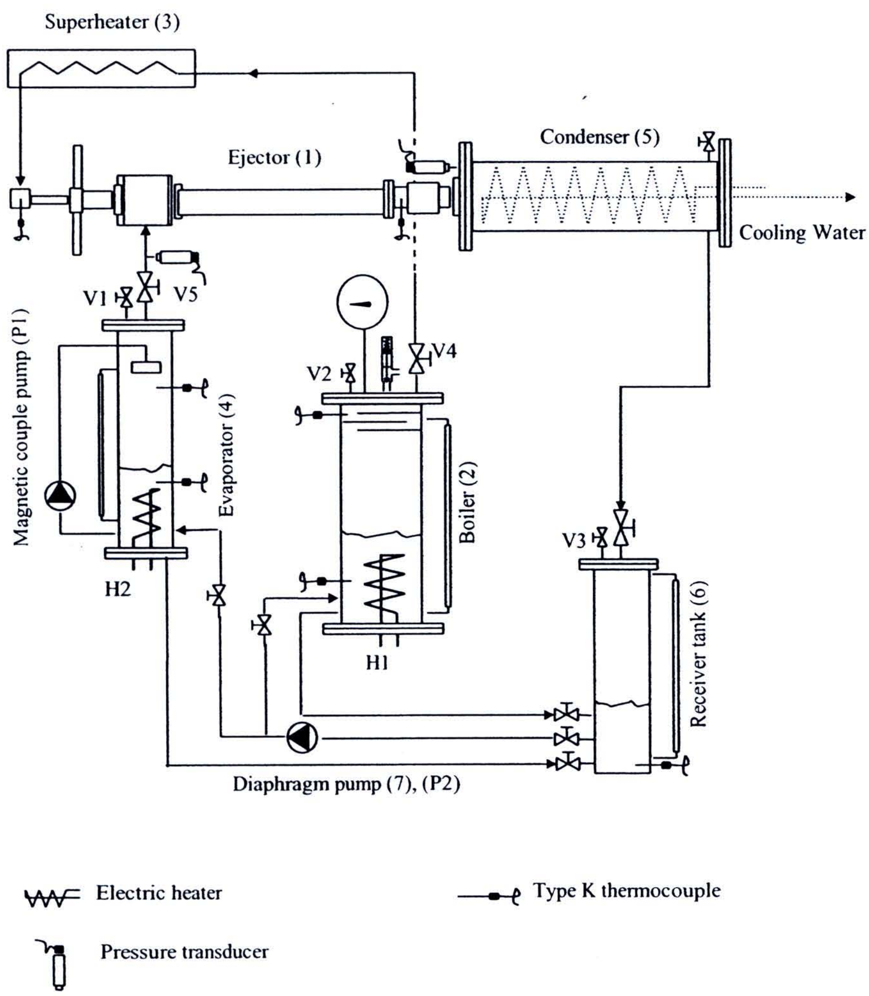

Figure 3.1: The schematic diagram of experimental steam jet refrigerator.

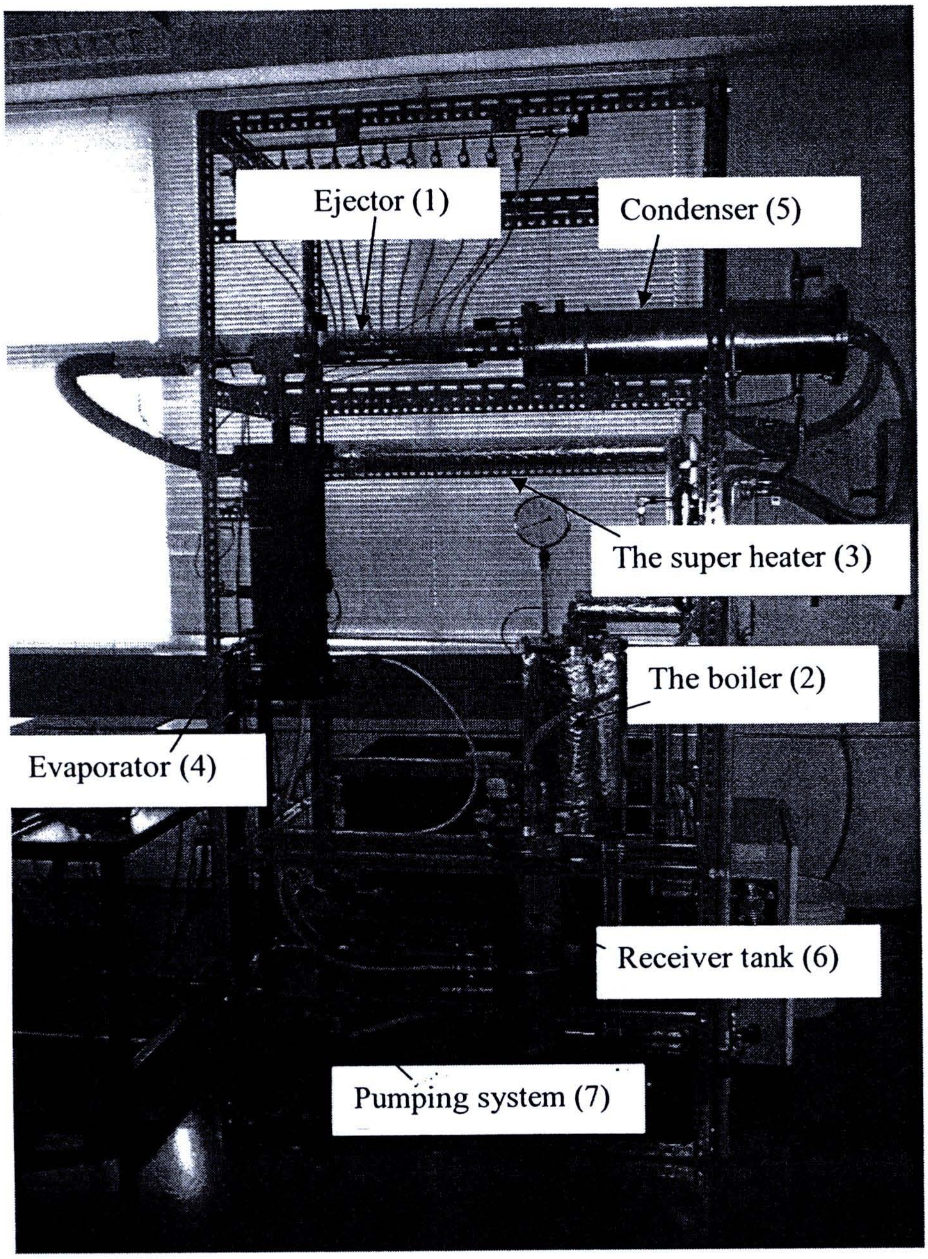

Figure 3.2: The experimental steam jet refrigerator.

The system was designed to produce a cooling capacity of 1 kW. The boiler maximum capacity was 8 kW. Electric heaters were used to simulate the cooling load at the evaporator and as the heat input for the boiler. The electrical heated boiler and evaporator were simple to construct, design, and control. The condenser was cooled by water.

The experimental refrigerator consists of seven principle components: (1) the ejector, (2) the boiler, (3) the super heater, (4) the evaporator, (5) the condenser, (6) the receiver tank, and (7) the pumping system.

At the boiler, two electric immersion heaters with total power of 8 kW were used as simulated heat source. The boiler was covered with glass fiber wool with aluminum foil backing to minimize the thermal loss.

The evaporator was designed based on a spray column. A small magnetic-couple pump was used to circulate the water (refrigerant) within the evaporator. The spray shower was located at the top of the evaporator. This was to promote the evaporation rate of water at very low pressure. A single 2 kW electric immersion heater was used to simulate the cooling load. The evaporator's shell was well insulated by poly-foam rubber, from an unexpected heat gain from the environment.

The condenser was designed based on a shell and coil heat exchanger. It was cooled by water. The cooling water was supplied by a 15 kW water chiller. The cooling water temperature could be controlled to temperature from 15 to 30°C. This allowed the experimental refrigerator to be tested with a wide range of condenser saturation temperature and pressure. The receiver tank was used to collect the liquid condensate from the condenser. The liquid condensate collected in the receiver tank was pumped to the boiler and the evaporator by a pneumatic diaphragm pump.

A 500 W superheater was used to superheat the saturated steam before entering the primary nozzle of the ejector. This was to ensure that there was no liquid droplet carried with the primary steam.

3.2 The ejector

The experimental steam ejector consists of 4 components which are the primary nozzle, the mixing chamber, the constant area throat, and the subsonic diffuser, as shown in figure 3.3. All geometries and dimension of the steam ejector were based on the mechanical design as recommended by ESDU [28].

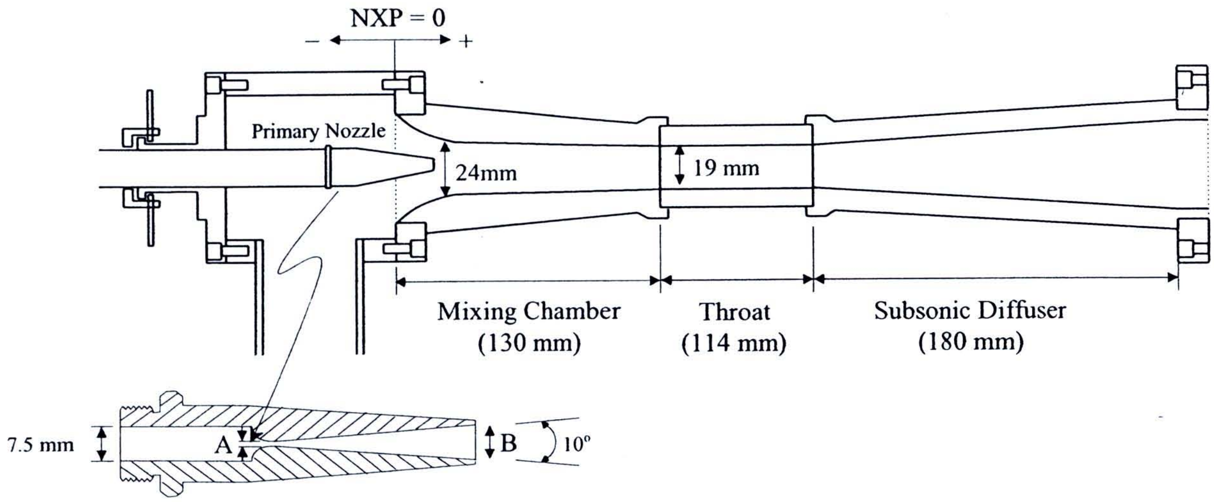

Figure 3.3: The experimental steam ejector.

In this study, only one fixed geometries ejector body was used. Three primary nozzles with throat diameter from 1.4, 1.7, and 2.0 mm were used as shown in table 3.1. All nozzles have the area ratio of 1:20 which provided an exit Mach number of 4.0. The nozzle was placed at an NXP of + 23 mm. An NXP (nozzle exit position) has positive value when the nozzle exit plane is inside the ejector inlet plane and vice versa.

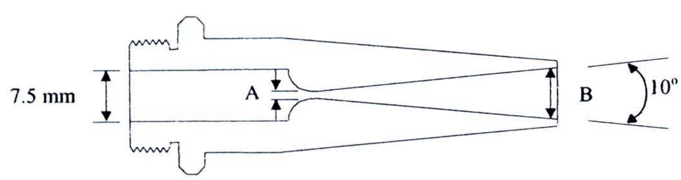

Table 3.1: The dimensions of the primary nozzle.

Nozzle	A (mm)	B (mm)	Area Ratio $(A/B)^2$	Calculated Mach number
1.	1.40	6.40	1:20	4
2.	1.70	7.60	1:20	4
3.	2.00	9.00	1:20	4

3.3 Instrumentation and control

Type k thermo couple probes were used to detect all the interested positions as shown in figure 3.1. All probes were calibrated with a precision mercury thermometer. Pressures at the condenser and at the evaporator were detected by absolute pressure transducers (0-250 mbar-abs). All transducers were calibrated with a double stage liquid-ring vacuum pump as an absolute zero pressure and a mercury manometer for a higher pressure. Atmospheric pressure was obtained from a precision mercury barometer.

The liquid saturation temperatures and pressures in the boiler and in the evaporator were controlled by applying the on/off (using digital thermostats) to the respective heaters. The saturation pressure of the condenser was controlled by adjusting the cooling water flow rate via a flow control valve and a solenoid valve. The solenoid valve was controlled by a pressure transducer.

Liquid levels in all vessels were observed by attached sight-glasses. When the system was operated continuously, liquid from the receiver tank was fed to the boiler and to the evaporator via a pneumatic diaphragm pump. Liquid levels in each vessel were controlled by infrared sensors and solenoid valves. The infrared sensors were attached to the sight-glasses.

Flow rate of high pressure steam at the boiler (ejector's primary fluid) was obtained by measuring the decreasing rate of the liquid level via the attached sight glass, during this, the make-up water was off. The same procedure was also applied in order to obtain the evaporation rate at the evaporator (ejector's secondary fluid). This allowed the evaluation of the ejector entrainment ratio at the particular operating condition.

Parameters to be measured and controlled while the system was operated were temperature, pressure and mass flow rate of the refrigerant.

3.4 Experimental procedure

The evaporator, the boiler, and the receiver tank were charged with deionized water. Each vessel was filled to approximately half way up a sight glass or to an amount sufficient to immerse the electric heating elements.

A two-stage liquid-ring vacuum pump is used to remove all non-condensable gases. Then, the boiler is isolated from the rest of the system by closing valve V_1, V_2, and V_3. Then, the boilers heaters (H1) are switched on. Wait until the preset temperature is reached. The heaters powers are controlled automatically by the digital thermostat. Then, open valve V_4 to allow the high pressure steam to enter the primary nozzle of the ejector.

Without any cooling water flowing through the condenser coils, the condenser temperature is increased rapidly. The cooling water is turned on in order to maintain a constant pressure in the condenser. The cooling water flow rate is regulated by on-off solenoid valve which is controlled automatically by a pressure transducer.

At the evaporator, the recirculation pump (P_1) is switched on. As the saturation temperature of the water in the evaporator continues to drop, the electric heater (H_2) is turned on. This heater power is also controlled automatically by the digital thermostat. Therefore, the liquid temperature in the evaporator is maintained constant at the preset value.

Since, the liquid level in the boiler and in the evaporator are monitored by infra-red switches, the condensate collected at the bottom of the receiver tank is automatically pumped back through pump (P_2) to the boiler and to the evaporator.

If the evaporation rates of the liquid in the boiler and in the evaporator are needed, the infra-red switch will be switched off. This allows the liquid level in each vessel to drop over a time interval. The dropping rate of liquid level in the boiler and the evaporator will be converted to the mass flow rate of primary fluid and secondary fluid, respectively. It can be considered as entrainment ratio of a steam ejector.

In order to avoid wet steam at the primary nozzle inlet, the superheater may be switched on. Electric power input to the superheater is adjusted in order to superheat the saturated steam from the boiler before entering the primary nozzle. Superheated by 1 or 2°C helps ensure that the primary steam remains dry otherwise there is no advantage.

3.5 Conclusions

Methods of design and construction of the experimental refrigerator were described. The experimental refrigerator was designed to be fully automatically controlled. The system was designed to provide a cooling capacity up to 1 kW. Electric heaters were used as the heat source for the boiler and as the cooling load for the evaporator due to the fact that they were easy to control and their power were easy to measure.