APPENDIX A

Developments of the experimental set-up

Before being assembled as an experimental refrigerator, as used in the study, which was described in chapter 3, several system configurations were constructed and tested. During the modifications, components were redesigned and changed so that it could be operated as required. This appendix describes design and construction process of the experimental DAR. Problems found are also discussed.

1. The first configuration

A schematic diagram of the experimental DAR in the first configuration is shown in figure A.1. This configuration was arranged so that the liquefied refrigerant from the condenser would be accumulated in the trap. Inside the trap, there was an arrangement of piping so as to prevent helium flowing upward from the evaporator into the condenser during operation. The liquid refrigerant could flow into the evaporator so as to be vaporized. There was an electric heater installed in the evaporator. It was used to supply heat as a simulated cooling load. Its power was convenient to be adjusted while being operated via the DAQ system. The amount of heat supplied by the heater could be measured precisely using a power transducer connected to the DAQ system. Evaporation of liquid refrigerant in the evaporator resulted from boiling. Therefore, cooling effect could be quantified accurately.

In the system described above, the experimental DAR had a pipe connecting the evaporator and the absorber. It was located around 100 mm below the top of both the evaporator and the absorber. The connected pipe was located at the high level position to prevent overflowed liquid refrigerant from the evaporator to the absorber during its operation. The pipe was designed for the auxiliary gas and vaporized ammonia to flow between the evaporator and the absorber. Therefore, the evaporated ammonia could flow from the evaporator to be absorbed by the falling film of the strong solution in the absorber. The auxiliary gas could flow back and forth between the absorber and the evaporator.

During system commissioning, this design configuration failed to operate. No cooling effect was produced at the evaporator. However, some coolness occurred at the trap, which could be sensed by touching. It appeared at the beginning period of operation. It was observed that there was circulation of the solution in the system. It was observed via sight glasses at the absorber. When applying heat to the electric heater at the evaporator, the liquid refrigerant was boiled. Evaporated ammonia caused rising of pressure inside the evaporator and absorber. Pressure inside the evaporator and absorber might be greater than that in the condenser. This could be realized from observation that the liquid refrigerant stopped flowing downward from the trap tank. When heating the evaporator was halted for a while, flowing was continued.

The test rig was modified to solve these problems. It must be disassembled. Before charging a new batch of working fluid the system must evacuated. During disassembly of sight glasses, sealing material (o-ring) was found to be damaged. It was found that sealing material had deformed. The sealing material was made up from VITON, which is normally used as it can withstand high temperature application. It was firstly selected for use with system components that must be operated with high temperature such as separator, rectifier. It was found that VITON could not be used in any application using any form of ammonia. It was replaced by EPDM, which was claimed to be compatible with ammonia vapor, liquid ammonia, and aqueous ammonia.

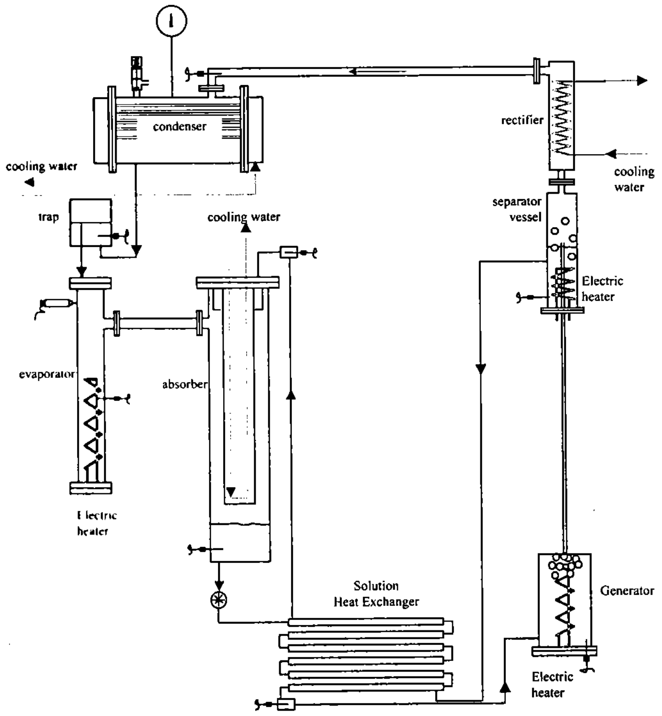

Figure A.1 The first configuration of the experimental DAR.

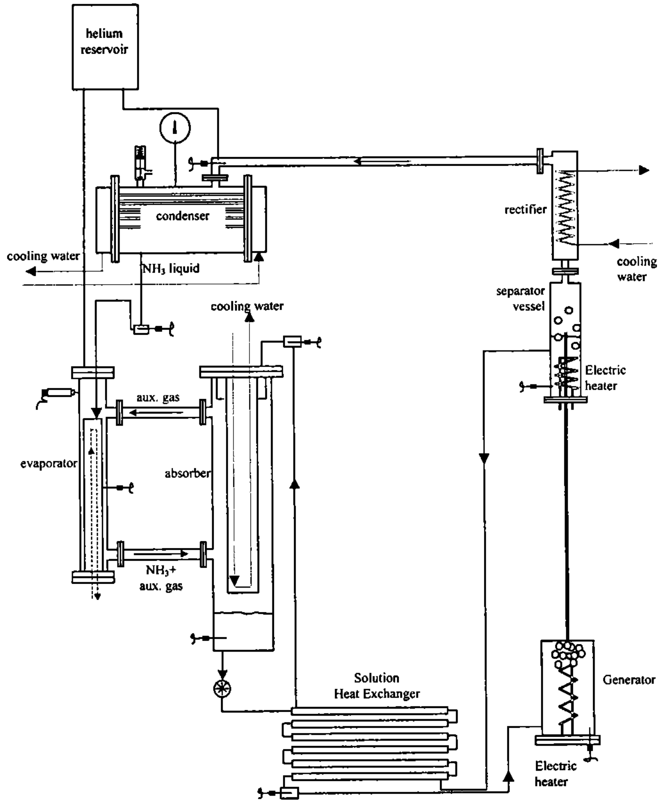

Figure A.2 The second configuration of the experimental DAR.

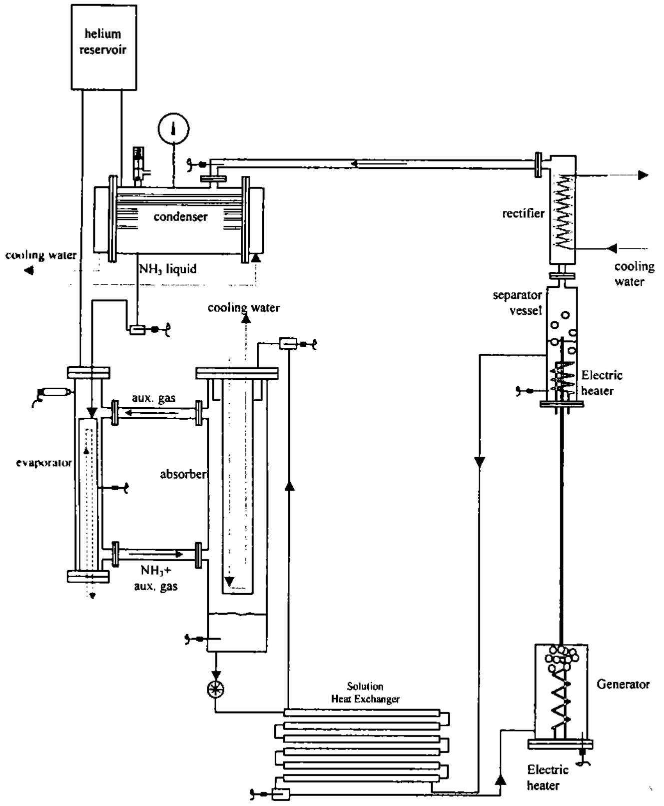

Figure A.3 The third configuration of the experimental DAR.

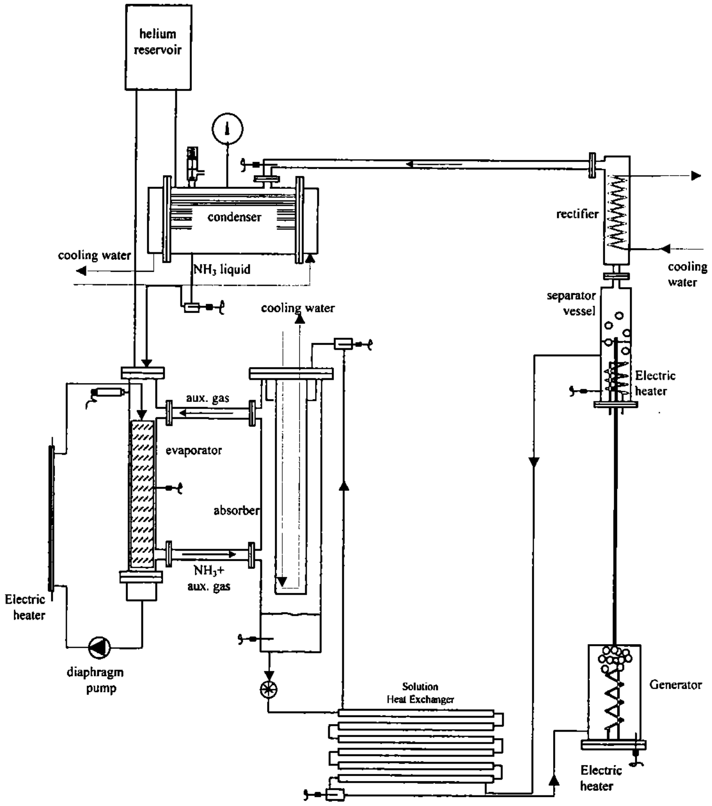

Figure A.4 The fourth configuration of the experimental DAR.

2. The second configuration

In the first design, coolness occurred at the trap tank. This was an undesirable phenomenon, as coolness should appear at the evaporator not at the trap tank. Moreover, it should take time for liquid ammonia to have enough volume that could flow down to the evaporator. As the liquid refrigerant in the trap tank was slowly increased therefore, the trap tank was removed. Knowing later that evaporation of liquid ammonia in the DAR is similar to evaporation of water from wet cloth and is definitely different from evaporation due to boiling of liquid. Therefore, evaporation of liquid ammonia in the DAR requires good mass transfer mechanisms. It requires evaporation surface area, period of absorption, different concentration, and flowing velocity of the auxiliary gas. To improve gas circulation in the system, an additional pipe connecting the evaporator and the absorber was installed around 10cm higher than the bottom of the evaporator horizontally to the absorber.

The evaporated ammonia mixes with the auxiliary gas and becomes heavier. It flows downward in the evaporator passing through the lower pipe into the absorber. In the absorber, ammonia vapor is absorbed by the strong solution flowing down as falling film. After the ammonia vapor was absorbed, the auxiliary gas became relatively lighter. Then, it flows upward to the top of absorber and flows back through the higher pipe into the evaporator. The gas circulation is established and mass transfer mechanisms can be enhanced.

With this design configuration, the liquid refrigerant cannot be accumulated in the evaporator. Therefore, the electric heater inside the evaporator was taken out. If there is liquid refrigerant accumulated, it will flow through the lower pipe into the absorber. So, cooling effect should be quantified by a different manner.

A 2in-pipe column was inserted vertically into the evaporator instead of the electric heater. There was an arrangement of flowing path for water circulation inside the pipe. Cooling effect from evaporation of ammonia in the evaporator would transfer to the water circulating inside the pipe. External surface of the inserted pipe were grooved to increase flowing period of the liquid refrigerant.

Referring to figure A.2, there was a tank installed at the top of the test rig. It was used as a helium storage tank. At the bottom, there were two small pipes connected. One was connected to the elbow pipe above the condenser, the other was connected to the top of the evaporator. These two tubes were used as pressure equalizing tubes between evaporator-absorber and the condenser. With these tubes, flowing of liquid refrigerant could be continued as a result of difference in the elevation. The trap tank was removed and a u-tube was installed as a trap between the condenser and the evaporator instead. It was used to prevent flowing of helium from the evaporator into the condenser during the operation

With this design configuration, a cooling effect occurred at the evaporator. There was ice formed at the outer surface of the evaporator after being operated for a while. The lower pipe connecting the evaporator and absorber was cool while the other was warm. It could be ensured that there must be circulation of the working fluid in these two pipes. Helium after absorption process flowed through the higher one. This could be implied from warming of the higher pipe as a result of absorption heat coming up with helium. Evaporated ammonia and helium flowed through the lower one. It could be implied from coolness appearing at the lower pipe. Cooling effect occurred in the evaporator due to evaporation of liquid ammonia.

It was noticed that the ammonia was not completely evaporated. The unevaporated ammonia was passed into the absorber together with evaporated ammonia and helium. For a few hours of operation, a pressure-equalizing tube connected to the evaporator was warm. It was found that heat was transferred from the helium reservoir. It was traced further and found that heat was transferred from the elbow pipe above the condenser. As there was a flow of rectified vapor from the rectifier through this pipe into the condenser. Heat coming up with the rectified vapor was transferred to the helium reservoir. It was transferred further into the evaporator through the pressure equalizing tube. This was an undesired effect, as it became an additional heat load for the evaporator.

3. The third configuration

According to the prior design configuration, unwanted internal heat was transferred to the evaporator. The heat originated from the rectified refrigerant vapor leaving the rectifier. It was transferred through a pressure equalizing tube connected at the elbow pipe above the condenser. Therefore, the end of this tube that was connected to the elbow pipe was moved. Its connected position was moved to the top of condenser instead. Knowing that condensation temperature of the refrigerant vapor in the condenser was maintained by cooling water temperature. Its temperature was certainly lower than that at the elbow pipe.

With this design configuration, the system was found to work properly. However, heat transfer through the column pipe inserted inside the evaporator was not adequate. Some liquid refrigerant flowed along the grooved column pipe and was spin out due to high velocity flow along the helix-grooved surface. Then, the liquid refrigerant was not totally evaporated on the external surface of the grooved pipe. This caused a reduction of the cooling capacity. Moreover, heat transfer between the evaporated refrigerant in the evaporator and water circulated inside the grooved pipe should be poor due to the thickness of the inserted pipe.

4. The fourth configuration

Due to poor heat transfer at the evaporator, the system configuration was focused on the mechanism of heat transfer in the evaporator. Cooling capacity that would be obtained from evaporation of liquid ammonia in the evaporator should be quantified. Therefore, an electric heater was installed to supply a quantified heat load for the refrigerant. It was known from the prior design that heat could not be supplied directly when the ammonia was being evaporated. Therefore, it was supplied to the liquid refrigerant before being evaporated. After the evaporation process, the temperature of the liquid refrigerant should be reduced by evaporation of liquid ammonia in the evaporator.

The cooling capacity could be quantified directly from the power of heat supply by the electric heater. To enhance the mass transfer, the grooved pipe was removed. Raschig rings; hollowed porcelain cylinders, were loaded into the evaporator column instead. These rings were used to retard flow of liquid refrigerant through the evaporator. Therefore, flow period of liquid refrigerant was prolonged. It extended the evaporation period and increased the evaporation surface area, which resulted in better evaporation rate of ammonia.

Refer to figure A.4, there was a small cap at bottom of the evaporator. It was used to accumulate the remaining liquid refrigerant after evaporation in the evaporator through the ceramic fills. This liquid was pumped via a diaphragm pump through a heat exchanger with an electric heater inside. Heat supply from the heater was directly transferred to the cooled liquid refrigerant. The amount of heat was measured by a power transducer connected via the data acquisition system. The heated liquid refrigerant was pumped and sprayed into the evaporator at the top over the fills. It was then evaporated reducing refrigerant temperature while flowing downward over the fills.

However, during the test, the diaphragm pump leaked as one of its rubber diaphragms was torn. Therefore, this design configuration has not completely operated yet. It was considered that the diaphragm might be torn by cracked parts of raschig rings. The cracked ceramics were hard and had sharp edges, which could damage the rubber diaphragm. Therefore, it might not be convenient to include the diaphragm pump into the system. Moreover, the pump parts had to be imported, which required some period of delivery time. If it was damaged again, it would not be convenient.

5. The fifth configuration

In the fourth configuration, the cooling effect extraction procedure was done by use of an electric heater. However, there was leakage of the diaphragm pump. Another problem was the bubble pump performance, which was discovered later during the system commissioning.

During the tests, input heat at the generator was varied. It was once abruptly increased from low to high power in order to observe the system response. It was found that after sudden increment of input power at the generator, the solution was stopped flowing for a while. It could be seen by observation through sight glasses at the absorber. It was noticed that temperature at top of the generator was rather high comparing to that before abrupt heating. During the system disassembly, it was found that the heater in the generator was burnt. Burnt surface was noticed at the higher end of the heater.

The heater might be exposed to the gas, which was generated and accumulated at the top portion of the generator. Knowing that vapor phase has lower heat capacity than that of liquid phase, if heat dissipated from the heater was too high to be transferred out properly, the heater would burn by its exceeding power. A sudden increment of heat input tended to cause intermittent pumping effect of the bubble pump. Then, the generator was reconfigured in order to solve this problem. From the first 4 design configurations, the generator was erected as shown schematically in figure A.1 to A.4. In this design configuration, the generator was laid horizontally and fixed at the lowest level of the set-up as possible so as to maximize the head ratio as much as possible. In the generator, the pump tube configuration was rearranged. A tube was used for vaporized solution to flow. One of its ends was connected to the side of the generator, the other end was connected to the other tube at a t-connector. The second tube was used as a path for liquid solution to flow in. By this configuration, the bubble pump could be operated continuously.

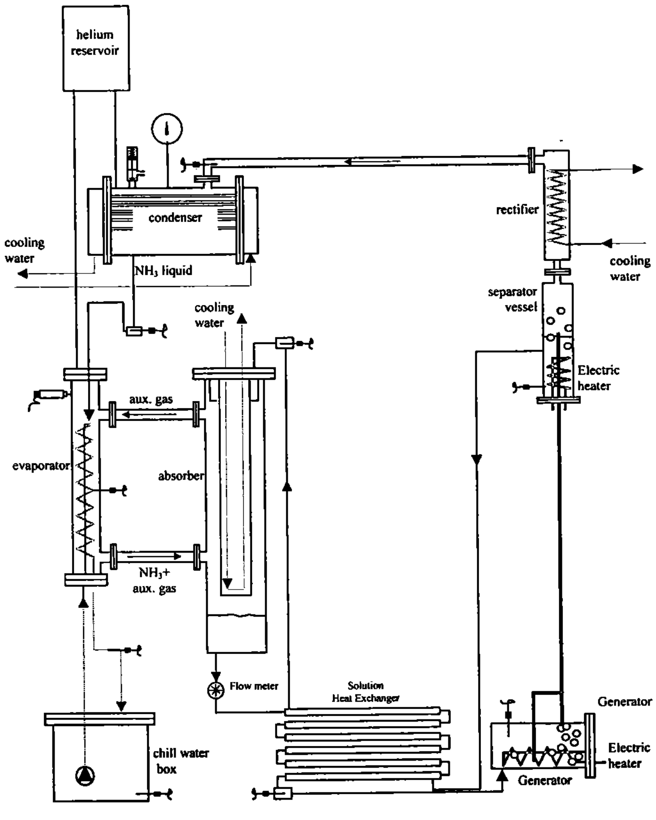

Figure A.5 The fifth configuration of the experimental DAR.

Due to exclusion of the diaphragm pump at the evaporator, transfer of the cooling effect was altered. A water chiller was installed instead of ceramic fills. In the evaporator, a 3/8in tube of 6m long was coiled and put inside the evaporator. Fresh water was circulated inside the coiled tube so as to be chilled by evaporation of refrigerant at the outer tube surface. To circulate the chilled water, a small aquarium pump was put into the chilled water box. The chilled water was stored in an well-insulated icebox so as to prevent unwanted heat gain from the surroundings.

This design was the final version, which already described in chapter 3. All the tested results discussed throughout this thesis were obtained from this final design.