CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

An ejector is the most critical component in the jet refrigeration cycle. In order to improve the design and the operation of jet refrigerator, a clear understanding of the flow characteristics reflecting the performance of the ejector should be obtained.

From literature surveys on the past researches of ejectors, the flow behavior and the mixing process within the ejectors were complicated. The use of 1-D assumption only may not be adequate to improve the design and the operation of the ejector. Very few studies were made to reveal the flow characteristics in ejectors by various methods, i.e., the flow visualization and the CFD (Computational Fluid Dynamics). Moreover, their analytical results were not completed. Some of them were out of experimental ranges and some were unable to be applied for refrigeration applications.

In this study, the investigations on the performance and flow characteristics of the R141b ejector (in refrigeration application) at various operating conditions and various geometries were performed experimentally and theoretically. A small scale R141b ejector refrigerator was constructed and tested. The experimental ejectors were modeled and investigated theoretically using the Computational Fluid Dynamics (CFD) method. It was shown that the CFD results were successfully validated with the experimental results. Average errors of the predicted entrainment ratio and the critical back pressure were both found to be less than 9% and 2% respectively. Three types of the following information: the primary fluid’s mass flow rate, the static pressure distribution at the wall of the ejector, and the entrainment ratio including its critical back pressure, were used to validate the simulated model. It was verified that the CFD method is an efficient tool to predict the entrainment ratio and critical back pressure of the ejector.

After the correctness of the model was guaranteed, then other calculated information, which were the static pressure distribution along the ejector's axis, and the contours of Mach number, were used to represent the flow phenomena and the mixing behaviors in the R141b ejector. Hence, a new theory describing the flow and mixing process in the R141b ejector using the CFD's visualization was proposed.

Unlike past research on CFD investigation of the ejector, the advantage of using the static pressure distribution along the ejector's axis instead of the static pressure distribution at the wall was discussed. It was shown that the exact shocking positions and the fluctuations on the shock pattern could be better represented. With this advantage, the two series of oblique shocks were found in the simulation. The first series of oblique shock was found immediately after the primary nozzle exit attached to the jet core of the primary fluid. In the distance between the constant area throat and the diffuser, the second series of oblique shock, which is the shock of the mixed stream fluid, was investigated. Moreover, the differences in the flow structures between the R141b ejector and the steam ejector were investigated and reported according to the differences found in the flow states after the primary fluid leave the primary nozzle, the shock phenomena occurs before the pressure recovery region, and the pressure recovery process.

In Chapter VII and Chapter VIII, the influences of the operating conditions and the ejector's geometries on the flow characteristics reflecting the ejector performance were reported, respectively. With help of the CFD solution and visualization, a better understanding of the flow characteristics and the performance of the R141b ejector as impacted by various operating conditions and geometries were obtained.

It was proved that the CFD's prediction provided similar results of performance characteristics curves compared to the experimental investigation and the typical performance curves of the ejector as discussed in the literature. At each setting of vapour-generator and evaporator condition, increasing the downstream pressure caused the operation of the R141b ejector to be categorized into 3 regions, the choked flow, the un-choked flow and the reversed flow of secondary fluid with respect to the change in the entrainment ratio. Within the choked flow region where the entrainment ratio remained constant, the effective area was always forced to occur somewhere in the constant-area throat section. For the ejector operated in the unchoked flow condition, the increase in the downstream pressure caused the second series of oblique shock to move upstream and disturb the entrainment process. The effective area was also pushed back into the convergent mixing chamber part where the cross sectional area of the effective area and, hence, the entrainment ratio can be varied according to the shape of the mixing chamber.

When the ejector was operated with various upstream operating conditions including the upstream conditions of the primary fluid (vapour-generator saturation pressure) and secondary fluid (evaporator saturation pressure), the parameters of upstream operating conditions could be combined into a single parameter called the upstream pressure ratio (P_S/P_P). This upstream pressure ratio altered the primary flow state at the primary nozzle exit's plane. The primary flow state can be classified into two states which are the "Over-expansion state" and the "Under-expansion state". The difference in the states of the primary flow was found to affect the flow field of the ejector and, hence, alter the ejector's performance. In an over-expansion state, the expansion wave angle of the primary fluid jet core converged into the axis line of the ejector. Thus, a smaller primary fluid jet core and a larger effective area were produced. It can be said that in order to obtain a better performance ejector, the ejector should be designed and operated so that the primary flow state is in an over-expansion state.

At the different primary flow states, the change in the ejector's operating conditions and geometries could affect the flow and the performance of the R141b ejector in different ways, as can be concluded in Table 9.1.

Table 9.1 Effect of operating conditions and geometries on the R141b ejector.

Primary flow state	**Effect Parameters**	**action**	**Performance Characteristic**	
			Entrainment ratio **(Rm)**	Critical back pressure **(P_C)**
<u>Effect of Operating Conditions</u>				
Over-expansion	Primary fluid saturation pressure	(-)→ (+)	↑	↑
	Secondary fluid saturation pressure	(-)→ (+)	↑	↑
	Primary nozzle throat diameter	(-)→ (+)	↓	↑
	Mixing chamber inlet diameter	(-)→ (+)	**unchanged**	**unchanged**
	Throat Length	(-)→ (+)	**unchanged**	↑
	NXP	(-)→ (+)	↑	↑
<u>Effect of Geometry Variations</u>				
Under-expansion	Primary fluid saturation pressure	(-)→ (+)	↓	↑
	Secondary fluid saturation pressure	(-)→ (+)	↑	↑
	Primary nozzle throat diameter	(-)→ (+)	↓	↑
	Mixing chamber inlet diameter	(-)→ (+)	**unchanged**	**unchanged**
	Throat Length	(-)→ (+)	**unchanged**	↑
	NXP	(-)→ (+)	↓	↑

According to the results, the design and operation of the ejector should be as following:

- The ejector should be designed and operated so that the primary flow state is always in an over-expansion state.
- In order to produce a small jet core or a large effective area, the throat diameter of the primary nozzle should be designed as small as possible. But the total momentum of the mixed stream should still be enough for the ejector to operate as close as the critical downstream pressure.
- The ejector with a longer throat section can be operated at a higher downstream pressure without any changes in its entrainment ratio. However, if the ejector is equipped with too long throat section, the loss in total pressure may mitigate its advantage on the downstream pressure which the mixed stream can emit.
- The diffuser of the R141b ejector and all halocarbon refrigerant driven ejectors can be designed into a very short length diffuser necessary to cover a narrow pressure recovery zone (effect of strong oblique shock).
- The enhancement of both the entrainment ratio and the critical back pressure can be obtained by moving the nozzle exit position (NXP) downstream into the mixing chamber when the primary flow state is in the over-expansion state.

The conclusion drawn from this research is that the CFD method is an efficient tool to predict the performance of the ejector including the entrainment ratio and the critical back pressure. The validation of the CFD results of the simulated model compared to the experimental results was fascinated. The flow characteristics reflected the performance of the ejector at various operating conditions and geometries were revealed. Finally, it is expected that the information provided in this thesis will lead to the improvement in the design and the operation of the ejector used in refrigeration applications, thus, increase the performance of the overall system.

9.2 Recommendations

It can be said that the CFD study of the ejector in this research was one of the first studies in the field of refrigeration purpose. In order to utilize this method more efficiently in modeling a flow in any ejectors, the followings are needed.

- The exit of the CFD domain should be extended to include the section connected to the condenser. From the validation of static pressure distribution, the simulated static pressure recovering process at the diffuser part was occurring within a shorter distance than the actual distance in the experiment. At the exit of the diffuser the static pressure recovering process seemed to be incomplete. If the calculation domain is extended to the end of the connecting pipe, the model would become more realistic. Hence, the prediction of the critical back pressure will become more accurate.
- The real gas equations should be applied to the calculation model as the properties of the working fluid rather than using the perfect gas assumption.
- The heat transfer function at the wall surfaces that allows not only the investigation of heat transfer, but also of condensation during the process, should be turned on so that the model could be more realistic.
- Other substitute refrigerants such as R123 and R245fa could be used in the simulation and also in the experiment. The properties of R123 and R245fa are similar to R141b. Moreover, in practice, R123 and R245fa are more compatible to most sealing materials.