CHAPTER 7
EFFECT OF INTERESTED PARAMETER BY USING MACH CONTOUR

In this chapter, effects of condenser pressure, boiler saturation temperature, evaporator saturation temperature, and the primary nozzle's throat diameter to the system performance were analyzed by using filled contours of Mach number obtained from the CFD simulation. The results provided a better understanding of the effects of those parameters.

7.1 Effect of operating pressure to the ejector performance

Figure 7.1 shows the effect of the condenser pressure to the ejector performance which was obtained from CFD simulation. The primary nozzle with throat diameter of 2.0 mm (no.3) was used. The boiler and the evaporator saturation temperatures were fixed at 130°C and 7.5°C, respectively. Point A is the operation in the choked flow region. Point B is the operation at the critical condenser pressure. Point C is the operation in the unchoked flow region. Points D and E are the operation at the breakdown pressure and in the reversed flow region, respectively.

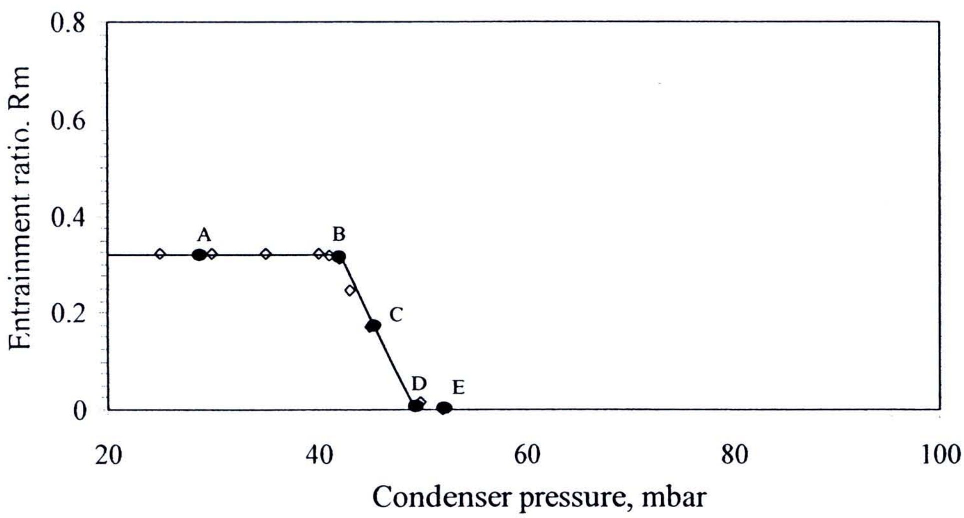

Figure 7.1: The effect of condenser saturation pressure.

Figure 7.2 shows the filled contour of Mach number which represents the flow inside the steam ejector which relates to the point A to E corresponding to figure 7.1. It can be seen that an increasing of the condenser pressure from A to E causes the *2nd shocking* position to move backward into the constant area throat section. If the back pressure does not exceed the critical value or operates in the choked flow region (A and B), the shock will not affect the mixing behavior of the two fluid streams. The secondary fluid is choked at some section called an *effective area*. This results the entrainment ratio to be constant over this region.

If the condenser pressure is higher than the critical value or operates in the unchoked flow region (C), the 2nd shocking moves closer to the region where the mixing process occurred. In this case, the mixing process is disturbed by the shock. As a result, the secondary fluid is no longer choked in the mixing chamber. Thus, the ejector entrains less amount of the secondary fluid. The entrainment ratio is dropped sharply in this region when the condenser pressure is continued to increase

If the back pressure is further increased to the breakdown value (D), the shock will move toward the primary nozzle and disturb the mixing process until the secondary fluid can not be entrained, thus, the entrainment ratio drops to zero.

If the back pressure is increased higher than the breakdown value, the ejector is in the reversed flow region (E). It can be seen that the shock will move closer to the primary nozzle and disturbs the primary fluid jet stream. The expanded wave can not be produced. The primary fluid jet stream is forced back to the entrance of the secondary fluid. This results the hot primary fluid from the boiler to reverse back to the evaporator.

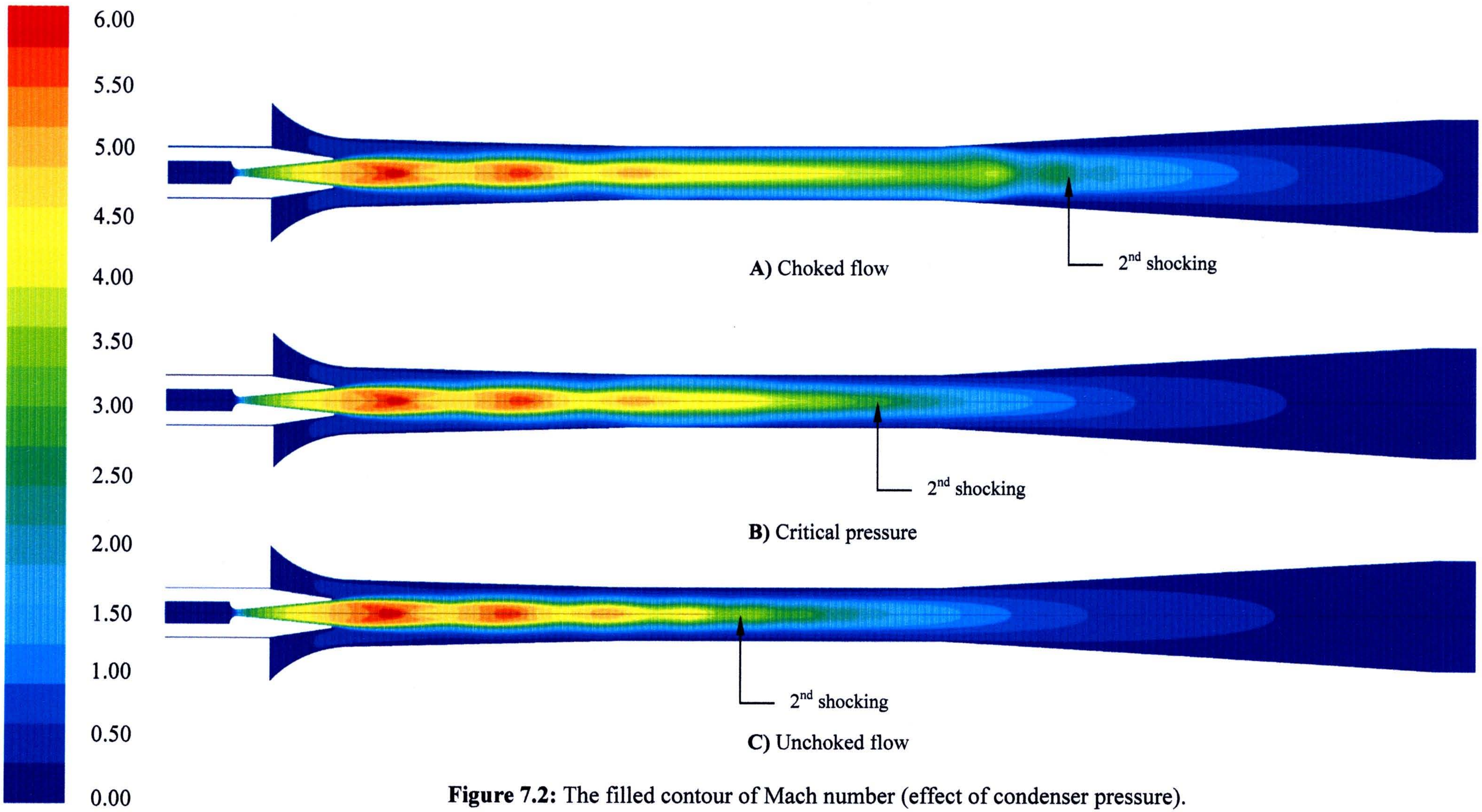

Figure 7.2: The filled contour of Mach number (effect of condenser pressure).

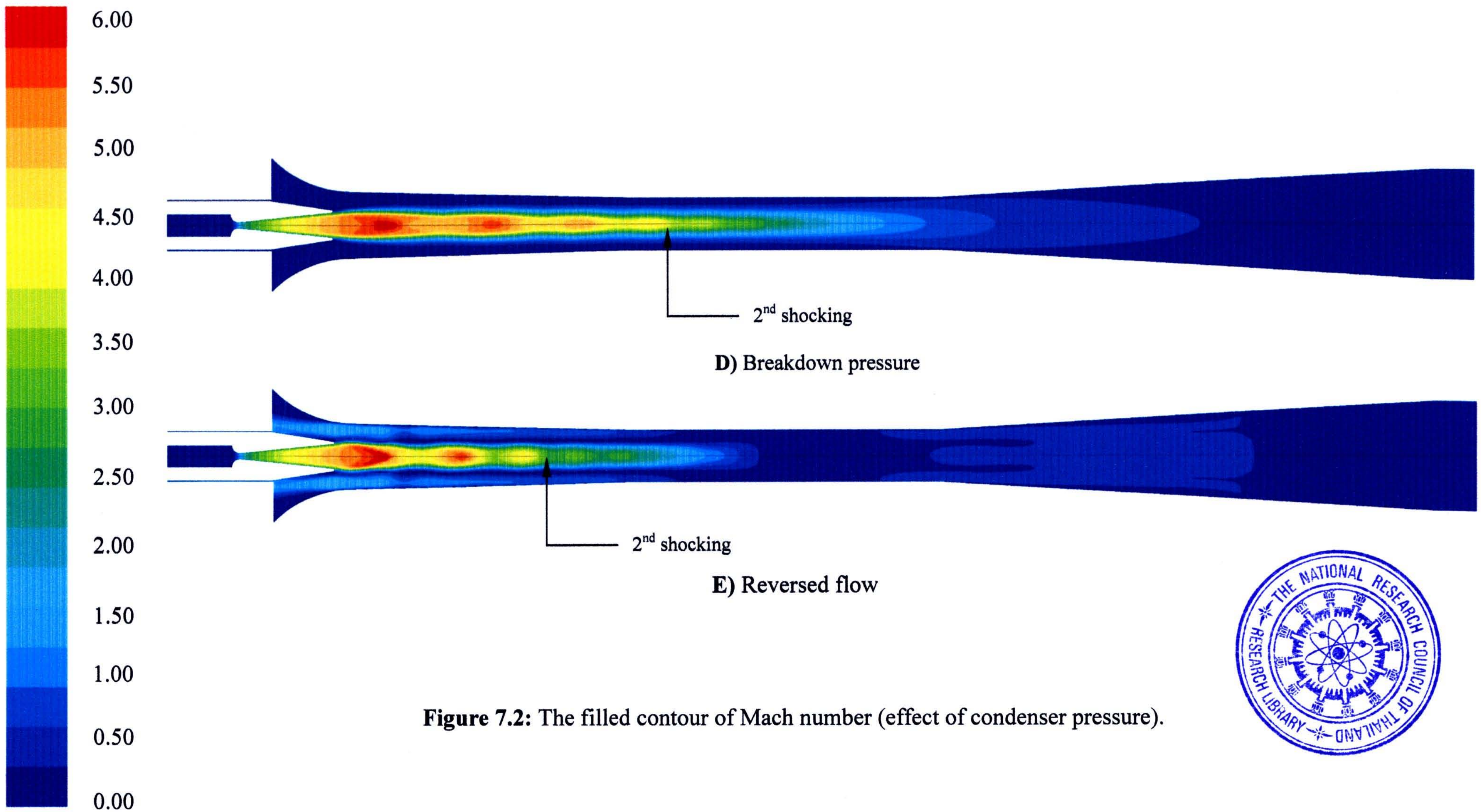

Figure 7.2: The filled contour of Mach number (effect of condenser pressure).

Figure 7.3 shows the effect of the boiler saturation temperature on the ejector performance which was obtained from CFD simulation. The primary nozzle with throat diameter of 2.0 mm (no.3) was used. The evaporator saturation temperature was fixed at 7.5°C. Three values of boiler saturation temperatures were used, 130, 140, and 150°C.

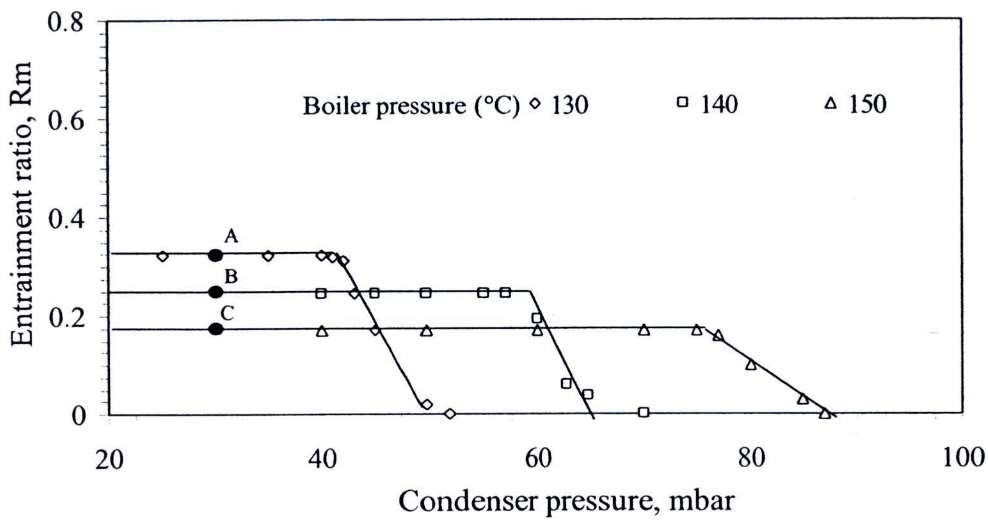

Figure 7.3: The effect of boiler saturation temperature.

Figure 7.4 shows the filled contour of Mach number which represents the flow behavior inside the ejector under condition for point A, B, and C. It can be seen that when increase the boiler saturation temperature, the expansion angle of the *expanded-wave* is increased. This is a result of the increase in momentum of the primary fluid jet stream (since the primary fluid mass flow rate is increased with the boiler saturation temperature). As a result, a narrower converging duct and a smaller effective area for the secondary fluid are produced. A less amount of the secondary flow rate is entrained into the mixing chamber. That means, when there is an increase in the boiler saturation temperature, the ejector entrains a smaller amount of the secondary fluid while the primary fluid mass flow is increased. The overall result is a reduction in the entrainment ratio.

Since the primary fluid jet stream flows with a higher momentum at a high boiler saturation temperature (due to the larger amount of the primary mass flow rate), the *2nd shocking* is moved forward to the subsonic diffuser and the ejector can be operated at a higher critical condenser pressure.

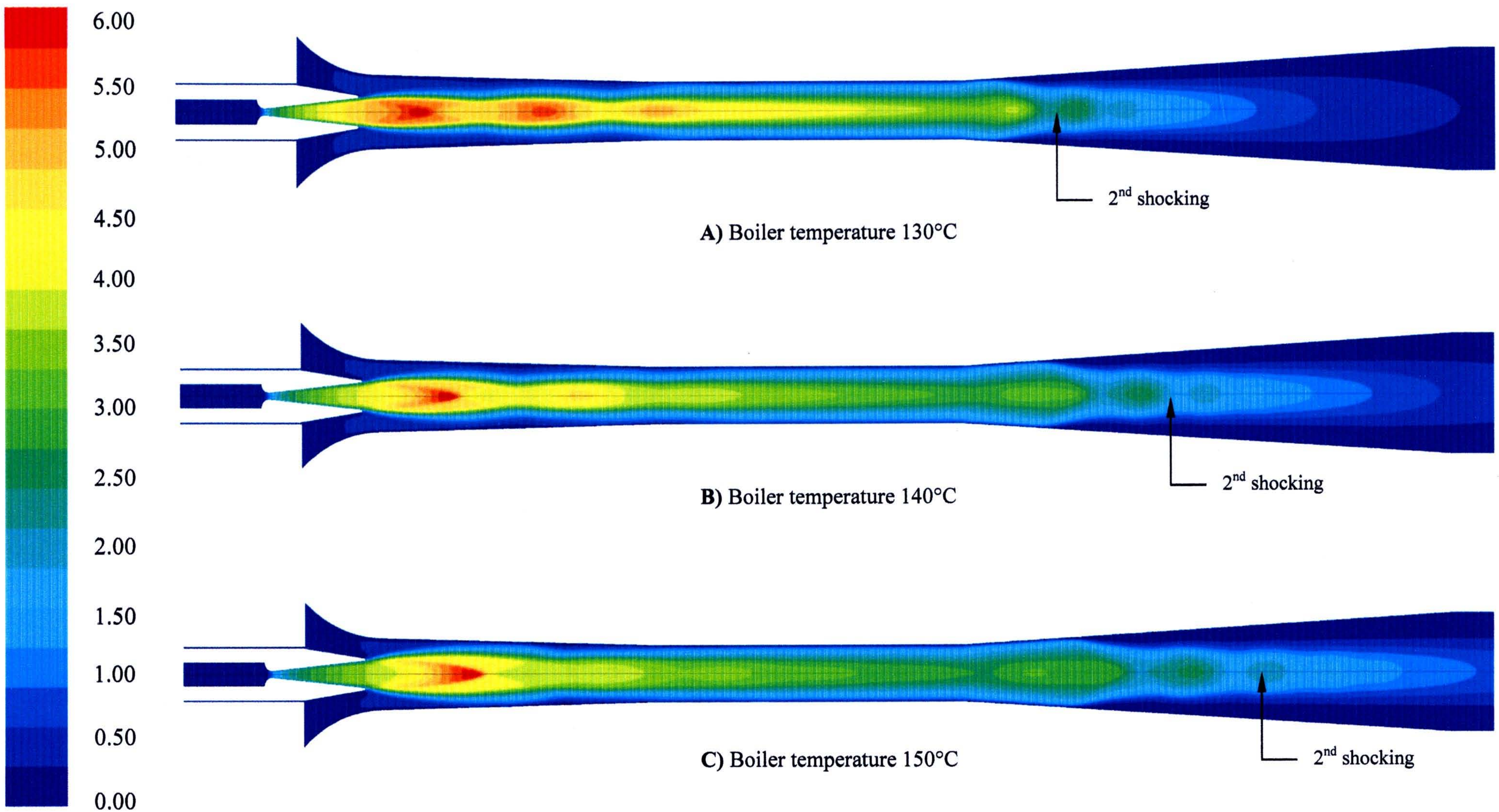

Figure 7.4: The filled contour of Mach number (effect of boiler saturation temperature).

Figure 7.5 shows the effect of the evaporator saturation temperature on the ejector performance which was obtained from CFD simulation. Only the primary nozzle with throat diameter of 2.0 mm (no.3) was used. The boiler saturation temperature was fixed at 130°C. Three value of evaporator saturation temperatures were used, 5, 7.5, and 10°C.

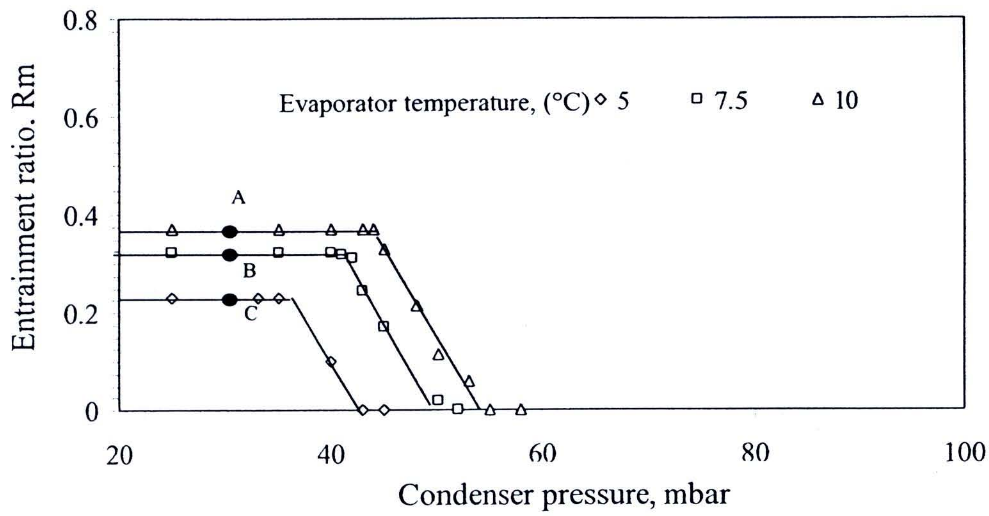

Figure 7.5: The effect of evaporator saturation temperature.

Figure 7.6 shows the filled contour of Mach number which represents the flow behavior inside the ejector under condition for points A, B, and C. It can be seen that an increase in the evaporator saturation temperature causes the *expended-wave* of the primary fluid to flow with a narrower expansion angle. This is a result of a higher mixing chamber pressure when the evaporator saturation temperature is increased. Since a narrower primary fluid jet stream is formed, a larger converging duct and a larger effective area for the secondary fluid are produced. Therefore, the larger amount of the secondary fluid can be entrained into the mixing chamber. The final result is the entrainment ratio is increased.

Moreover, figure 7.6 also shows that that the increase of the evaporator saturation temperature causes the *under-expanded wave* (A) to be transformed to the *over-expanded wave* (B) as can be noticed from the reduction of the expansion angle [18]. As a result of transformation from under to over expanded, the primary fluid jet stream is more uniform at a higher evaporator saturation temperature. A better mixing process of the two fluid streams at a higher pressure (due to an increase of the evaporator pressure) is resulted. This results in the *2nd shocking* to move forward to the subsonic diffuser and the ejector can be operated at the higher critical condenser pressure.

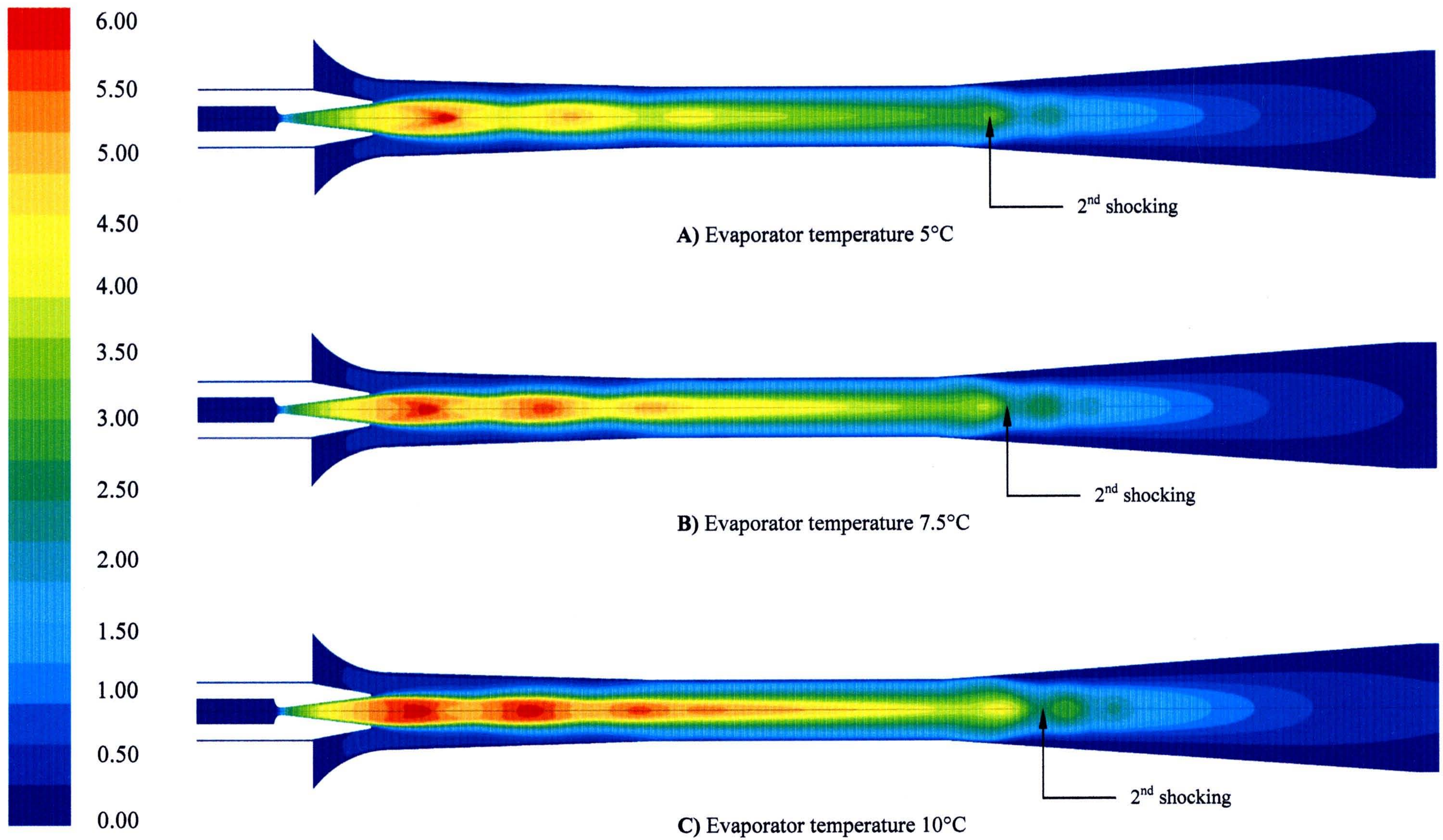

Figure 7.6: The filled contour of Mach number (effect of evaporator saturation temperature).

7.2 Effect of primary nozzle's throat diameter

Figure 7.7 shows the effect of the primary nozzle's throat diameter on the ejector performance which was obtained from CFD simulation. The boiler and the evaporator saturation temperatures were fixed at 150°C and 7.5°C, respectively. Three primary nozzles were used which were of 1.4 mm (no.1), 1.7 mm (no.2), and 2.0 mm (no.3). These nozzles produced the same exit Mach number of 4.0.

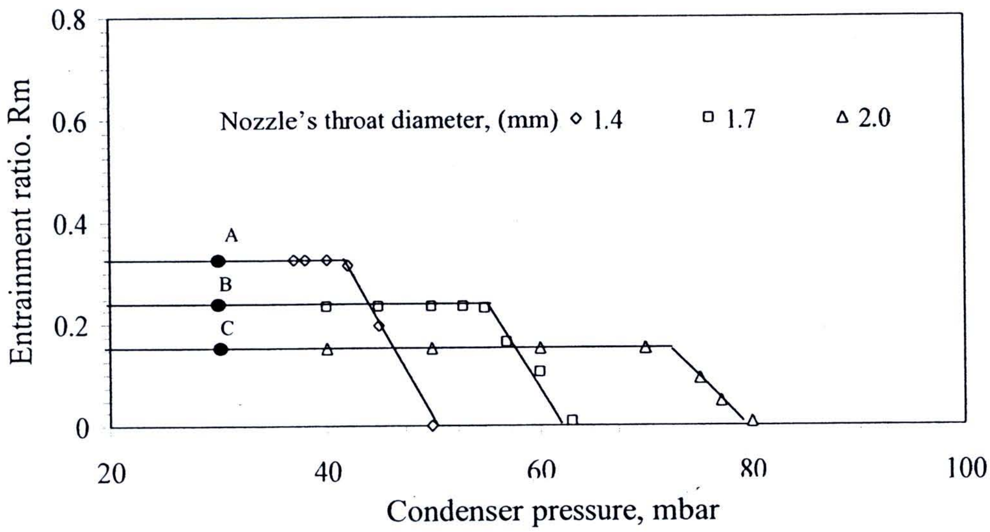

Figure 7.7: The effect of primary nozzle's throat diameter.

Figure 7.8 shows the filled contour of Mach number which represents the flow behavior inside the ejector under condition at point A, B, and C. It can be seen that when a larger nozzle is used, the expanded wave is produced with a larger expansion angle. This is a result of a larger momentum of the jet stream. This is due to the fact that, a nozzle with larger throat will allow a greater amount of the primary fluid critical mass flow rate to pass through the primary nozzle.

From the figure, it can be seen that, a narrower converging duct and a smaller effective area are produced when a large nozzle is used. Therefore, less amount of the secondary flow is entrained into the mixing chamber. In addition the higher momentum of the primary fluid jet stream also causes the *2nd shocking* to move forward to subsonic diffuser. This results the ejector to be able to operate at a higher critical condenser pressure. It can be said that, using the primary nozzle with large throat will produce the same effects as the boiler is operated at a higher saturation temperature.

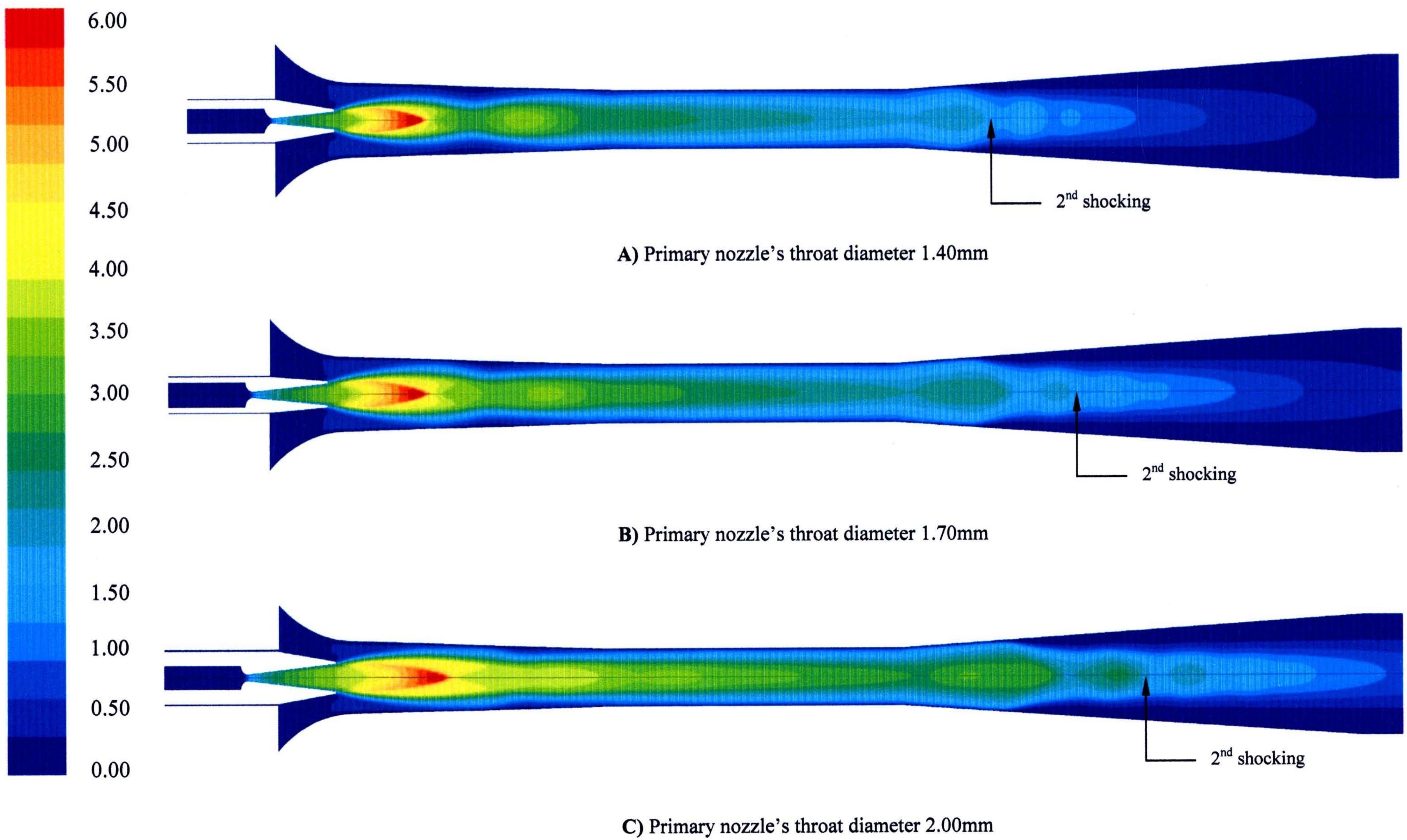

Figure 7.8: The filled contour of Mach number (effect of primary nozzle's throat diameter).

7.3 Conclusion

In this chapter, effects of condenser pressure, boiler saturation temperature, evaporator saturation temperature, and the primary throat diameter to the ejector performance were explained by using the fill contours of Mach number obtained from CFD simulation.

The fill contour of Mach number showed that when the condenser pressure is increased but not greater then the critical value, the primary fluid jet stream flows with the same momentum (both mass flow and speed are fixed) and expansion angle of the expanded wave. This results in the converging duct for the secondary flow (formed by the primary fluid jet stream and the mixing chamber wall) and effective area for the secondary fluid to remain unchanged. The shocking position move backward to the ejector's upstream but does not disturb the mixing process. Therefore, the entrainment ratio remains constant in this choked flow region. When increases the condenser pressure greater then the critical value but lower than the break down value, the primary fluid jet stream remains the same but the shocking position is moved closer to the primary nozzle. The mixing process is disturbed by the shock. This causes the ejector to entrain smaller amount of the secondary fluid. The entrainment ratio drops sharply.

The expansion angle of the primary fluid jet stream is varied when changed the boiler saturation temperature, evaporator saturation temperature, or using different nozzles. This will change the size of the converging duct for the secondary flow. This results in the entrainment rate of the secondary fluid (and the entrainment ratio) to be varied. The larger converging duct and an effective area allow greater amount of the secondary fluid to be entrained into the mixing chamber and vice versa. A narrow expansion angle of primary fluid jet stream will be produced when the boiler saturation temperature is low, or the evaporator saturation temperature is high, or using a small nozzle. It was also found that, the 2nd shocking position is also varied when changed. The shocking position is related to the critical condenser pressure. When the shocking is moved forward to the subsonic diffuser, the ejector can be operated at a higher critical condenser pressure and vice versa. The shocking position will move toward the subsonic diffuser when the momentum of the mixed fluids (secondary and primary fluids) is high. This occurs when increase the primary fluid mass flow rate (using a larger nozzle or increase the boiler saturation temperature) or by increasing the ejector upstream pressure (evaporator saturation temperature).

An increase of the boiler saturation temperature or the use of a large nozzle allows more primary fluid through the primary nozzle. The primary fluid jet stream flows with a high momentum and with a large expansion angle (smaller effective area). The shocking position will move toward the subsonic diffuser. The overall results are; the entrainment ratio is decreased (the ejector entrains less amount of the secondary fluid while the primary fluid mass flow is increased) and the ejector can be operated at a higher critical condenser pressure.

An increase of the evaporator saturation temperature will increase the ejector's upstream pressure. This reduces the expansion angle of the primary fluid jet stream (larger effective area). The shocking position is pushed toward the subsonic diffuser. The overall results are; the entrainment ratio is increased (more secondary fluid is entrained while the primary fluid mass flow remains unchanged) and the ejector can be operated at a higher critical condenser pressure.

The filled contour of Mach number obtained from CFD simulation can be used to explain the mixing process in the ejector. A better understanding will lead to a better design of the ejector.