CHAPTER 6
THE FLOW BEHAVIOR INSIDE THE STEAM EJECTOR

In the previous chapter, the CFD model was used to predict the performance (entrainment ratio and critical condenser pressure) of the tested ejector. The simulated results were compared and validated with the actual values (obtained experimentally). It was found that the CFD model provided exceptional results compared with the actual value. In this chapter, the flow behavior and mixing process inside the steam ejector will be explained by the graphical results from the CFD simulations. The filled contour of the Mach number which represents the flow behavior inside the steam ejector is presented.

6.1 The flow inside the steam ejector

The example of the Mach number filled contour obtained from the CFD model is presented in figure 6.1. The boiler saturation temperature is 130°C, the evaporator saturation is 5°C, and the condenser saturation pressure is 30mbar.

From the figure, as high temperature, high pressure fluid known as "primary fluid" enters the primary nozzle; the fluid is accelerated in the converging portion of primary nozzle (1). At the nozzle's throat, the Mach number is unity and the flow is choked. The flow is further accelerated to supersonic level in the diverging part of the nozzle (2). At the exit plane, the primary fluid leaves the primary nozzle as a supersonic stream which flows under the free boundary pressure condition. Therefore, the expanded wave with some value of expansion angle is formed [18]. This expanded wave is classified as two characteristics which are *under-expanded wave* and *over-expanded wave* which are presented in figure 6.2.

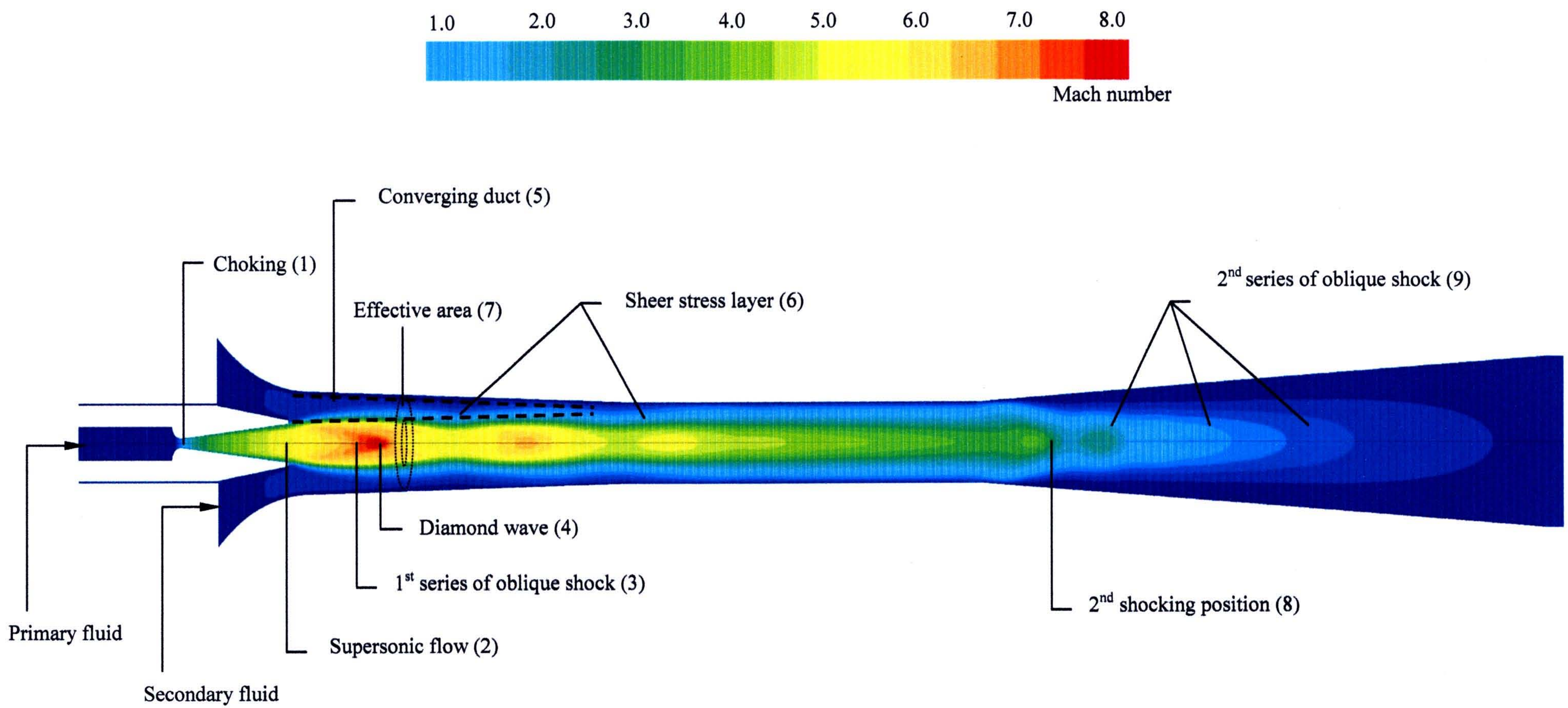
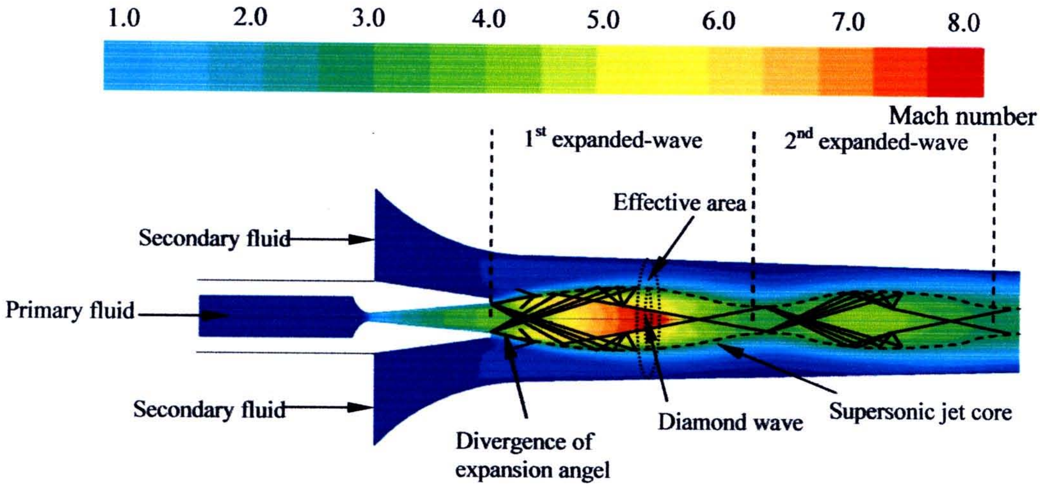
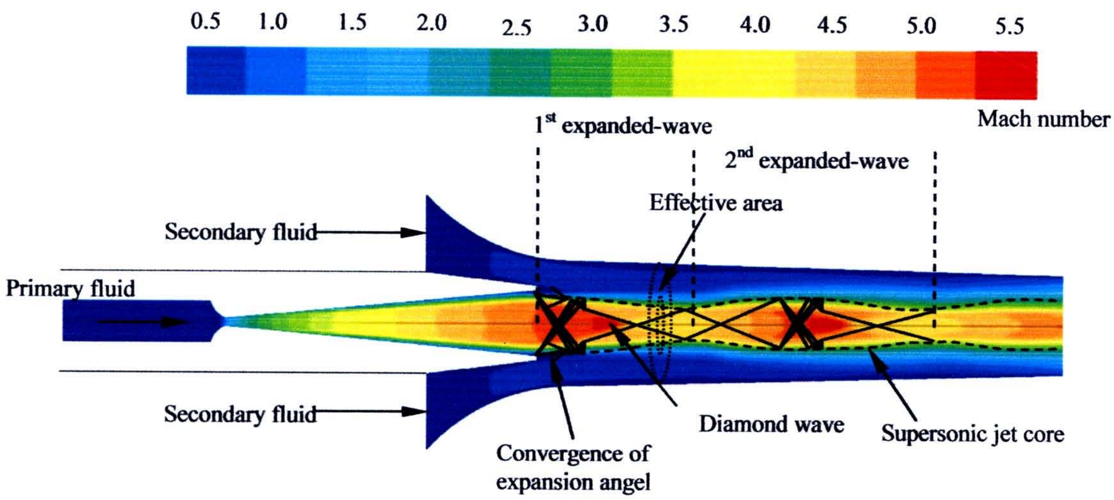


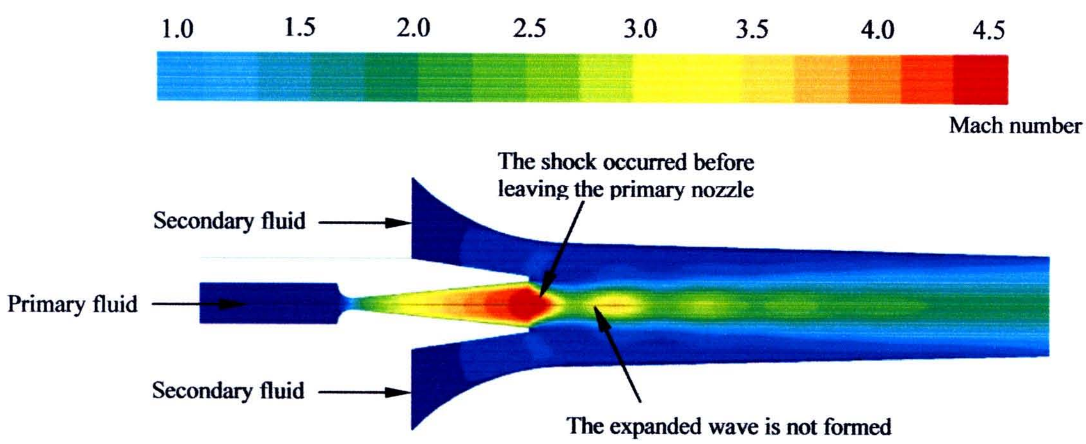
Figure 6.1: The filled contour of Mach number represents the flow inside the steam ejector.



a) The under-expanded wave.



b) The over-expanded wave.



c) The malfunction of ejector.

Figure 6.2: The difference of the expanded-wave.

In the case of *under-expanded wave*, the primary stream will leave the primary nozzle with divergence of expansion angle as shown in figure 6.2a. This case is occurred when the static pressure at exit plane of the nozzle is greater than that in the mixing chamber pressure [18]. It results in the jet stream to be further expanded after leaving the nozzle exit plane. The Mach number is increased to a higher value. The expansion angle and supersonic level are dependent on the differential pressure between the pressure at the nozzle exit plane and that in the mixing chamber [18]. As the *under-expanded wave* is being produced, an *oblique shocks* simultaneously occurred. This causes the Mach number of the jet stream to increase and a *diamond wave* is formed. In the second expanded wave the Mach number drops and the diamond wave disappears.

In the case of *over-expanded wave*, the primary stream will leave the primary nozzle with convergence of expansion angel as shown in figure 6.2b. This case occurs when the static pressure at nozzle exit plane is lower than that in the mixing chamber [18]. Similar to the case of the *under-expanded wave*, an *oblique shocks* and a *diamond wave* is also produced. But, the oblique shock is not as strong as that for the case of *under-expanded wave*. Moreover, the oblique shock can be repeated along the jet core. Unlike the case of *under-expanded wave*, Mach number of the jet core remains almost unchanged after the first expanded wave. If the mixing chamber pressure is too high, the supersonic jet stream will not be produced since a normal shock may be induced in the divergent part of the nozzle. The ejector is then malfunction as shown in figure 6.2c.

An *over-expanded wave* occurs when the primary fluid pressure is relatively low otherwise it will be an *under-expanded wave*. The jet core for the case of an *over-expanded wave* has less effect from the oblique shocks; therefore, the Mach number is more uniform. This results in a higher momentum in the jet core (primary fluid) which is more preferable to the ejector performance. If the primary fluid pressure is relatively high, the nozzle can be designed to produce a relatively high Mach number (large exit area); low pressure at the nozzle exit will be produced and results in an *over-expanded wave*. If the primary fluid pressure is not high enough, the nozzle must be designed to produce a lower Mach number (smaller exit area) which produces a higher exit pressure in order to promote an *under-expanded wave*, otherwise a normal shock will be induced and the ejector will be malfunction.

Referring to this figure 6.1, the oblique shock found in the expanded waved may be called *1st series of oblique shock* or *1st shocking*. It can be observed that the flow form is a semi-separation between the primary and secondary fluids. These fluids are not immediately mixed. Therefore, the *converging duct* (5) for entraining the secondary fluid is formed by the primary fluid jet core and the mixing chamber wall [9]. At the interface of the primary fluid jet core and the secondary fluid, due to the large velocity difference, the *shear stress layer* (6) is created. This causes the secondary fluid to be accelerated to sonic velocity and choked at some section along this converging duct. At the interface, some of the secondary fluid is gradually mixed with the primary fluid until the secondary flow reaches to sonic level. The secondary flow is then choked at some section (annular area formed by the primary fluid jet core and the mixing chamber wall) called *an effective area* (7). This can occur at any cross-section along the mixing chamber and is difficult to exactly specify this location. It depends on the operating-pressure of a steam ejector.

During the mixing process, the momentum of primary fluid is transferred to the secondary fluid. Thus, the primary stream is gradually retarded which can be observed by the diamonds wave gradually disappear. Meanwhile, the secondary stream is gradually accelerated. As the mixed flow passes through the constant area section, due to the high downstream pressure, a series of oblique shocks is induced (8). This shock is called *2^nd^ series of oblique shock or 2^nd^ shocking.* As a result of this oblique shock series, the static pressure of mixed fluid is increased rapidly (9). The flow form is changed from supersonic to subsonic. In the subsonic diffuser section, the mixed flow is further slowed down to almost stagnation in order to recover the static pressure before discharging to the condenser.

6.2 Conclusions

The study shows that, the primary stream is always choked at the primary nozzle throat. At the nozzle exit, the primary fluid leaves the nozzle as a supersonic jet stream which can be *under-expanded* or *over-expanded.* This depended on the pressures at the nozzle exit and that in the mixing chamber. In the expanded wave jet core, a series of oblique shocks called *1^{st} series of oblique shock* is found.

Due to large difference speed between primary stream and secondary stream, the shear stress layer is created. This causes the entrained secondary fluid to accelerate to sonic speed at some cross section called an *effective area.*

As the mixed stream flow passes through the ejector's throat section, due to large difference pressure between mixed fluids and downstream, the *2^{nd} series of oblique shock* is induced. This is the major compression effect produced by the ejector. The mixed fluids rapidly change from supersonic to subsonic while its static pressure is also rapidly recovered. Static pressure of the mixed flow is further recovered in the subsonic diffuser.

It can be concluded that the processes and details of the flow inside the steam ejector can be clearly explained by using CFD simulation. The filled contour of Mach number was used to represent the flow behavior inside the steam ejector.