CHAPTER 7

Conclusion

The turbulent wall jet has been used in many industrial applications and is still the active area for research for improving the heat transfer rate. To enhance the heat transfer rate, this thesis includes the study of flow and thermal behaviour of turbulent wall jet flowing over a wavy wall. In doing so, the bottom wall is made wavy in the sinusoidal waveform. The amplitude of the wavy wall is varied from 0.0 to 0.8 and the frequency is varied from ω_4 to ω_{12} in the first part. In the second part, the wavy wall is modified into a partial wavy wall and a partially linearly decaying wavy wall. In these two parts, the study has been performed numerically using the low Reynolds number $k-\varepsilon$ RNG model. The experimental investigation has been done in the third part of the thesis, where the mean and fluctuating velocity and temperature have been measured for different amplitudes. In this part, the wavy wall is given adiabatic condition. The mean and fluctuating velocities are measured by a single probe hotwire anemometer; the wall temperature is captured through FLIR infrared camera and the mean and fluctuating temperatures in the flow field are measured by the k- type thermocouple. The conclusion drawn from the numerical and experimental results are mentioned here:

In the first part of the thesis, by changing the amplitude and frequency of wavy wall, it has been noted that the local maximum streamwise velocity increases with the increasing amplitude and frequency, in the near flow field region. At the first crest location, the maximum value of U_{max} is achieved. In the far field, the inner shear layer thickness increases as the amplitude of wavy wall increases. Whereas, the local maximum temperature and the length of the potential core decrease with increasing amplitude and frequency. The separation of flow is noticed for the frequency ω_6 and amplitude 0.8. Before that, the flow remains fully attached to the wall throughout the domain for all the amplitudes. The location at which separation is initiated for the first time moves towards the nozzle as the A and ω_N increase. The area under the re-circulation zone also keeps on increasing with the increasing A and ω_N and covers up to 58.2% of the total area for A=0.8 and ω_{12}. The influence of amplitude on heat transfer rate is more prominent in the near flow field. The local Nusselt number increases with the increasing amplitude till the location $X = 28$, $X = 23.5$ and $X = 15$, for ω_4, ω_8 and ω_{12} respectively. For ω_4, the influence of amplitude becomes negligible beyond $X = 28$. Whereas, the Nu_x starts decreasing for higher amplitudes and at the trough, the value even goes less than the value for the plane wall jet for frequency ω_8 and ω_{12}. For ω_{10}, the average Nusselt number increases with the increasing amplitude till 0.7 and then it reduces with further increase in the amplitude and the maximum increment in heat transfer rate is 19.08% with respect to the plane wall jet. For ω_{10}, when the losses due to increase in friction factor are included, the THP has been improved by 5.3% for the wavy wall of amplitude 0.8. For each frequency, the average Nusselt shows a quadratic relation with the amplitude. In comparison to the plane wall jet, the maximum heat transfer enhancement of 23.23% has been achieved for the wavy wall with ω_9 and A=0.7. Further increase in the amplitude and frequency increases the re-circulation zone, which reduces the heat transfer rate.

In the second part of the thesis, the wavy wall is modified in two different ways by keeping the frequency constant (ω_{10}), so that the separation and recirculation can be controlled and heat transfer can be increased further. In the first case, the wall is modified into a partial wavy wall, where a segment of wall from the leading edge is made wavy followed by a plane wall segment. And from the results, it has been noted that for a given % of partial wavy wall, as amplitude increases from 0.4 to 0.8, the formation of the developed zone is delayed, in plane wall region. In the plane wall region of the wavy wall, the local maximum streamwise velocity U_{max} is maximum for 10% wavy wall and it reduces further as the % of wavy portion increases indicating that the turbulence of jet is also maximum for 10 % wavy wall and it reduces further on increasing the % of wavy wall. When the fluid moves from wavy to plane wall region, the fluid enters into the transition zone before getting developed, because Y_{max} falls in that region which is similar to the trend of Y_{max} in the transition zone of fully plane wall case. The maximum heat transfer is observed for 30% wavy wall with the amplitude 0.8, which is 26.27% higher than the fully plane wall jet. The increase is much higher than the increment in heat transfer with a simple wavy wall. For the same frequency ω_{10}, the maximum increment in heat transfer rate is 18.8% for simple wavy wall. The THP increases with the increasing wavy wall portion for 0.2 and

0.4 amplitudes. In the case of 0.2 amplitude, the THP remains less than 1, which makes it unsuitable for heat transfer enhancement. By considering the losses, the maximum THP is 5.3% for 0.8 amplitude and 70% of wavy wall and it remains constant thereafter with increase in the wavy wall portion. In the second case, the wall is modified into a partially linearly decaying wavy wall, where a segment of wall from the leading edge is made with a constant amplitude 0.8 followed by a segment of LD wavy wall. From this study, it has been concluded that the U_{max} increases as the % of LD wavy wall increases and it is maximum for the case of 100% LD wavy wall. The growth of jet spread and the growth of the inner shear layer decrease with the increase in % of LD wavy wall. Similar to the velocity spread and the growth of the inner shear layer of the jet, the thermal spread and growth of Y_{Tmax} of jet also reduce with the increase in the % of LD wavy wall. In the region of LD wavy wall, the Reynolds stresses and heat flux increase with the increasing % of LD wavy wall, for a given location. There is a maximum increment of 27.9% in the heat transfer rate for the wavy wall with 100% LD wavy wall, which is higher than the previous study on a fully wavy wall jet. Moreover, the partially linearly decaying wavy wall gives the best THP among all the cases, which is 6.7% for 50% of LD wavy wall.

The third part of the thesis deals with the experimental and numerical analyses of turbulent wall jet flowing over an adiabatic wavy wall. In this case, the amplitude is changed from 0.2 to 0.6 and the results are compared with the results of the plane wall jet. The results show that self similar behaviour is noticed in the downstream direction and as the amplitude increases, the self similar behavior gets delayed. In the case of temperature profiles, the self similar temperature profile for the plane wall jet and for the trough location of wavy wall follow the Gaussian trend, whereas, for the crest location, Gaussian trend is not followed. The U_{max} follows the power law trend for the crest and trough separately in the developed region. The spreading of jet ($Y_{0.5}$) also becomes linear (similar to plane wall jet) at the crest and trough separately. The decay of wall temperature also follows the power law $\theta_W = AX^{-n}$ with a constant decay rate n, and the decay rate increases as the amplitude of wavy wall increases. In the near flow field, the amplitude of wavy wall has a great influence on the turbulence of the jet, because the turbulent intensity and power spectral density both increase with the increasing amplitude. This means that the intermixing of the jet also increases with the increasing amplitude. The temperature fluctuation is high near the exit of the jet (close to the wall) and it reduces as the fluid moves forward and becomes almost flat in the thermally developed region. The influence of wavy wall on the temperature fluctuation is felt in the near flow field only.