# Chapter 6

## Conclusion and recommendations

### 6.1 Conclusion

The cost associated with the replacement of heat exchangers is considerable. Therefore more intensified efforts are being made to predict flow-induced vibration. The literature study indicated that if the velocity through the heat exchanger could be predicted more accurately, the margin of uncertainty in predicting the vortex shedding, turbulence buffeting and fluid-elastic instability could be reduced. HTRI analyses can be used to determine if the heat exchanger will be within the 20 percent uncertainty range when the mass flow rate through the heat exchanger is increased. The problem with the HTRI analyses are the prediction of the mass flow rates associated with the excitation of the tubes due to vortex shedding, turbulence buffeting and fluid-elastic instability. The HTRI analyses do not take the flow patterns through the heat exchanger into account and the average cross-flow velocity that is used to calculate the excitation frequencies, is not representative of the velocities through the heat exchanger.

If the HTRI excitation frequency calculations at the increased load are between 0 and 80 percent of the natural frequency, the heat exchanger can be operated at the increased load without experiencing flow induced vibration. When the excitation frequency exceeds 80 percent of the natural frequency, additional methods are required to determine if vibration will occur.

The CFD analyses led to a better understanding of the flow velocities through the heat exchanger. The magnitude and direction of the cross-flow velocity, varies over the tube length. By using CFD analyses, more accurate cross-flow velocity values throughout the heat exchanger were obtained. In the case of the tail gas heat exchanger that was analysed, the HTRI results predicted the average cross-flow velocity 20 percent higher than the maximum average CFD cross-flow velocity (at the second tube row). By using CFD analyses, one can not only predict the flow velocities through the heat exchanger, but also predict where the velocities that could cause flow-induced vibration will occur. In the case of the tail gas heat exchanger, only a very small portion of the tubes are subjected to flow-induced vibration conditions. Modifying only a small section of the heat exchanger could easily solve this problem.

CFD analyses are expensive and in order to reduce the computational time the average cross-flow velocity values were used to obtain velocity equations. These equations can be used to calculate the magnitude of the cross-flow velocity at any given mass flow rate and position within the specified range. This reduced the computations to only four simulations, one at the lowest and one at the highest mass flow rate of the range for the inlet and middle section of the heat exchanger. These velocities can be used to calculate the excitation frequencies needed for the force distribution on the heat exchanger tubes. The dynamic pressure also varies due to vortex shedding, which causes alternating forces. This also needs to be taken into account. The effect that the force distribution has on the tube's vibration, can only be obtained if a complete fluid-structure interaction analysis is done on the unsupported tube length.

To determine the vibration amplitudes without doing a fluid-structure interaction analysis, the vibration of the heat exchanger was measured at different flow rates. The experimental results that were described in Chapter 4, confirmed that vibration did occur at the lowest natural frequency as predicted by the HTRI analysis. The measurements indicated that vibration (at the lowest natural frequency) occurred over the entire mass flow range that was measured. This is also in good correlation with the CFD analyses, which predicted that vibration would occur over a range of mass flow rates, and not at a single value, as predicted by the HTRI analyses. The measured vibration amplitude was very small and may not cause premature failure of the heat exchanger. Failure can only be predicted once a fatigue analysis is performed on the heat exchanger.

## 6.2 Recommendations and future work

### CFD work

By determining the correlation between the inlet velocity and the velocity distribution through the heat exchanger for different tube to pitch ratios, tube configurations, heat exchanger configurations and baffle configurations, more accurate vibration predictions can be made without the use of too many expensive CFD analyses.

In the CFD analyses, a problem was identified with flow over tubes in large structures. The number of cells that are needed to solve the problem and still obtain reasonable results became excessive. Due to limitations in computational power, only simulations with a mass flow rate lower than 25 kg/s could be solved. More computational power is needed if larger mass flow rates or structures need to be solved.

To determine if the forces on the tubes are sufficiently large to cause premature failure of the heat exchanger, fluid-structure interaction analyses and fatigue analyses should be performed.

**Experimental work**

The strain gauge measurements provided good results at lower frequencies, with the added advantage that strain gauges are inexpensive in comparison with accelerometers. Strain gauge measurements can therefore be used to monitor the vibration levels of a heat exchanger. These measurements are taken on the shell of the heat exchanger. Better measuring techniques are needed to determine the correlation between tube and shell, and tube and support vibration.

To quantify the margin of uncertainty in the prediction of flow-induced vibration, a more detailed analysis of the factors that influence the natural frequency of the tube, are needed. These include better correlation values for different tube configurations and heat exchanger configurations, as well as a better representation of flow velocities through the heat exchanger.